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BUDD-STANLEY ED-SET®

MODEL X4100

**TECHNICAL MANUAL
FOR DEMONSTRATION OF
ELECTROMAGNETIC RADIATION**

Edited by Dr. C. L. Andrews, Chairman,
Department of Physics,
State University of New York, College of Education

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Preface

The Budd-Stanley Ed-Set® Model X4100 has been specifically designed for use by secondary schools as part of the science program.

This manual has been prepared for the purpose of providing a ready source for the instructor of all the information necessary to integrate this instrument into his present course material. Included is complete data to effectively conduct scientific demonstrations and experiments which heretofore have been unavailable to secondary schools. Use of the "Chart of Electromagnetic Radiations" and the many diagrams of this manual will ensure obtaining the full potential of this educational instrument.

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Chapter 1

THE NATURE OF ELECTROMAGNETIC RADIATION

In order to understand electromagnetic radiation, there are a few basic electric and magnetic fundamentals which we must study. In space or any medium, lines of electric force occur about any charged particle. Figure 1 - 1 shows a negatively charged particle with the electric field lines about it. These lines, although they are imaginary, are the paths along which the charged particles travel. The measure of an electric field is called the field strength and is proportional to the ratio obtained by dividing the force, F , exerted on a small test charge, q , placed in the field, e.i., F/q . It would require a certain amount of work to move another charged particle through the field set up by the particle in Figure 1 - 1.

Associated with any moving electric charge there is another field or energy called the magnetic field. Figure 1 - 2 shows the magnetic field set up about a wire carrying a small current. The magnetic field lines are closed circles having no beginning or end such as electric lines have. Magnetic field strength is measured by the amount of torque required to turn a small, current carrying coil or magnet in the magnetic field causing the magnetic moment vector of the coil or magnet to line up with the magnetic-intensity vector of the magnetic field.

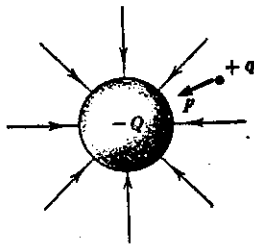


FIGURE 1 - 1

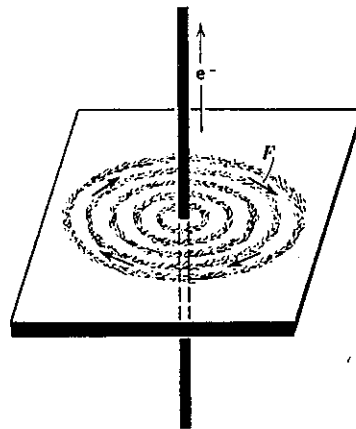


FIGURE 1 - 2

A wire carrying a current will have both an electric and a magnetic field set up about itself. If the current alternates in direction, as in the 60 cycle current we have in our houses, the direction of the electric and magnetic fields will also change each half cycle. The diagram in the upper left-hand corner of the "Chart of Electromagnetic Radiations" shows the configuration of this alternating field. This is an electromagnetic wave. Whenever a charged body vibrates, such a field is generated. The frequency of vibration determines the frequency of the electromagnetic wave and thus its position in the electromagnetic spectrum.

All electromagnetic waves behave in similar fashion and one can study the phenomena anywhere along the spectrum. We see light and its related phenomena each time we open our eyes. Since the visible portion of the spectrum is most familiar to us all, it is natural that we would study the electromagnetic effects in this portion of the spectrum. Because of the extremely short wavelengths, however, experiments with light are sometimes not too obvious to the student. Therefore, if we conducted our experiments in the radio wave portion of the spectrum, which is of lower frequency, and therefore of longer wavelength, a more simplified observation of these phenomena would be available.

The only thing which differentiates the electrical waves from the radio waves, infrared rays, visible light, ultra-violet rays, X-rays, and gamma rays, is the frequency associated with the vibrations in these portions of the spectrum. They all obey the laws which visible light obeys. In effect, by studying these laws in the radio wave, or more particularly, the microwave portion of the spectrum, we are duplicating the approach used by radio astronomers. The secrets of the universe are becoming more evident every day to our scientists through radio astronomy. Since the frequency range of radio waves is so much greater than that of visible light, a much larger percentage of the electromagnetic emissions of outer space is detectable. We are being provided with much more information than was previously available through strictly optical observations. Therefore, we shall talk about light but it is to be understood that the characteristics of light are identical with the characteristics of all electromagnetic radiations. Our experiments shall be carried out in the microwave portion of the spectrum. The Budd-Stanley Ed-Set® was designed specifically to simplify the demonstration of the principles of electromagnetic radiation.

During the seventeenth century, there were two major theories as to the nature of light, the Corpuscular Theory, developed by Sir Isaac Newton and the Wave Theory postulated by a Dutch physicist, Christian Huygens. Newton held that light consisted of tiny particles of matter (corpuscles) emitted from a source and propagated outward in straight lines. This theory failed to account satisfactorily for phenomena involving interference, diffraction and polarization. It also predicted an incorrect value for the speed of light in media other than air.

Huygens proposed that light consisted of wave trains having perpendicular wave fronts. The rays, which one sees emanating from a light source, he believed, were the lines of direction of the waves propagated from that source. Huygens' Wave Theory gradually achieved wider acceptance. It was particularly supported by the works of James Clark Maxwell.

Maxwell derived a wave equation from the known laws of electricity and magnetism of Ampere, Faraday and Gauss, indicating that light waves must be electromagnetic in nature. This Electromagnetic Wave Theory of light adequately accounted for all phenomena involved in the transmission of light. It described the behavior of light while being transmitted from a source to an absorbing body in any media. In 1886, Maxwell's Theory was confirmed as correct when Heinrich Hertz, a German physicist, first produced and detected long electromagnetic waves. It was found that these waves were similar to light and could be reflected, refracted, diffracted, and polarized. Newton's Corpuscular Theory was completely abandoned.

Maxwell's Theory gave an accurate description of the long waves produced by vibrating charges and current and yet it proved to be incapable of describing the processes of emission and absorption by molecules, atoms, and nuclei involved in the waves of higher frequency. Scientists discovered that light incident upon the surface of certain metals causes these metals to emit electrons at a rate proportional to the intensity of the light. This phenomenon is known as the Photoelectric Effect. According to the Wave Theory, an increase in intensity will result in an increase in the photoelectrons' velocity. The actual case, however, is that although more electrons are emitted per second, that these have the same group of discrete velocities as electrons emitted at the lower light intensity. The Corpuscular Theory failed to explain interference, etc. while the Wave Theory failed to explain the photoelectric effect.

In 1900, Max Planck, a German physicist, postulated his quantum hypothesis. He suggested that radiation of a certain frequency cannot be emitted or absorbed in arbitrary amounts but is always emitted or absorbed in discrete quantities, or quanta, of energy proportional to the frequency. Albert Einstein, in 1905, using the Quantum Theory was able to explain the Photoelectric Effect.

We can now create a complete picture of the characteristics of light. Propagation of light occurs by wave transfer to energy as in mechanical waves and in sound waves. Absorption or emission of light energy occurs at quantum levels which are proportional to the frequency of the energy. The packets of light emitted at these discrete quantum levels are called photons.

Based on Quantum Theory, the Danish physicist, Neils Bohr, postulated a theoretical model of the atom. He proposed that the extranuclear particles, or electrons, move about the nucleus in certain fixed orbits whose distances from the nucleus are determined by their energy. The larger the energy, the greater the distance of the orbit from the nucleus. Electrons remaining at the specified energies remain in the same orbit and radiation of energy cannot take place. When a surplus amount of energy is absorbed by the atom, the electron is caused to move to an orbit having a greater distance from the centralized nucleus. When this happens, the atom is in an unstable state and tends to radiate energy. Such radiation allows the electron to return to its original lower orbit. This energy is radiated in quantum units. Though this explanation does not consider the spin and angular momentum of the particles, it allows an elementary understanding of the atomic structure.

Atoms radiate energy in visible light, X-rays, and gamma rays. Visible light is radiated by jumps of outer-orbital electrons from a higher to a lower energy state. X-rays are generated by jumps of inner-orbital electrons. An S-ray quantum is of greater energy than a quantum of visible radiation, proving that more energy is needed to cause an inner-orbital electron to change orbits than that needed by an outer-orbital electron. This is to be expected because of the inverse square laws of electrostatics. The nuclei of atoms emit electromagnetic radiation as gamma rays and emit matter as Alpha and Beta particles. When the uranium atom begins its radioactive disintegration process leading to the stable element of lead, these radiations are observed. Your attention is here referred to the uranium atom pictured in the upper right-hand corner of the "Chart of Electromagnetic Radiations".

A French physicist, Louis de Broglie, proposed that the dual particle and wave nature of light was good evidence that all particles have a wave nature. By now, we are familiar with the energy-mass equation of Einstein: $E = mc^2$. Combining this equation with the equation giving the energy of a photon: $E = hf$, where h is Planck's Constant ($h = 6.624 \times 10^{-34}$ joule-second) and f is the frequency of the radiation, the wavelength of a photon may be expressed in terms of its mass by the equation $\lambda = h/mc$ where λ (lambda) is the Greek letter symbolic of wavelength. Any particle having a velocity v , will have an associated wavelength $\lambda = h/mv$.

Just as we are accustomed to thinking of light as consisting of waves, we are also accustomed to thinking of matter consisting of particles. Visible light and radio waves do not have a readily observable particle nature and particles that are large enough to be seen do not have a readily observable wave nature. The particle properties of radio-frequency photons are not apparent because only a very large number of photons can be detected. The wave properties of microscopic matter are not apparent because the wavelength is undetectably small. The dual properties of matter become quite apparent in the X-ray region. The X-ray photons show both particle and wave properties. Gamma rays show only the particle properties of the photons because of their small wavelengths. Slow electrons and neutrons have relatively long wavelengths and, therefore, show wave properties.

In this discussion, it is not meant to imply that there is no fundamental difference between photons and material particles. The most basic of all differences between the two is that a photon moves with the speed of light and the material particle must move at a speed which is less than that of light.

Chapter 2

UNDERSTANDING MICROWAVES

In the early days of World War II, Army scientists were working on a top-secret project which would enable our guns and bomb sights to be aimed without the operator actually seeing the target. Even the name RADAR was classified in those days. Since then, Radio Detection and Ranging, RADAR, has grown from crude transmitters and receivers to the complex airport approach systems and police radars of today. Television is an important result of this work in microwaves. Discoveries of good microwave energy generators and efficient transmission lines played a major role in this development.

At present, microwave frequencies range from about 1 KMC to 200 KMC. These high frequencies make possible the use of two unique but very practical devices, waveguides and cavity resonators. Essentially, waveguide is a hollow metallic pipe for transferring microwave energy. A cavity resonator is a hollow metallic cavity in which electromagnetic vibrations can exist when the cavity is properly excited.

The electrical energy transferred along a transmission line may be thought of as transmitted in either of two ways. First, it may be thought of as carried by electricity in the transmission lines. Second, it may be thought of as residing in the electric and magnetic fields that propagate along the transmission line.

While these two types of transfer of electrical energy appear entirely unrelated, scientists now tend to look upon two wire lines as elements which guide electromagnetic waves from one place to another. The currents present in these lines are considered incidental to the action and the resultant of the moving fields. If they are a quarter wavelength or more long, two-wire lines are poor guides for electromagnetic waves because the fields are not confined to the region of the wires. As shown in Figure 2 - 1 energy is lost in the perpendicular direction due to radiation. Should one conductor be extended around the other to form a coaxial cable, the field can be confined in all directions.

Energy transfer in coaxial cable is considered to take place by electromagnetic fields rather than current flow. However, at high frequencies, there is the disadvantage of the skin effect. The skin effect limits the current carrying area of a conductor

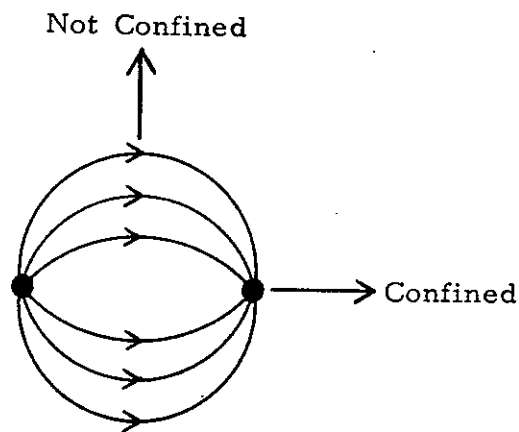


FIGURE 2 - 1

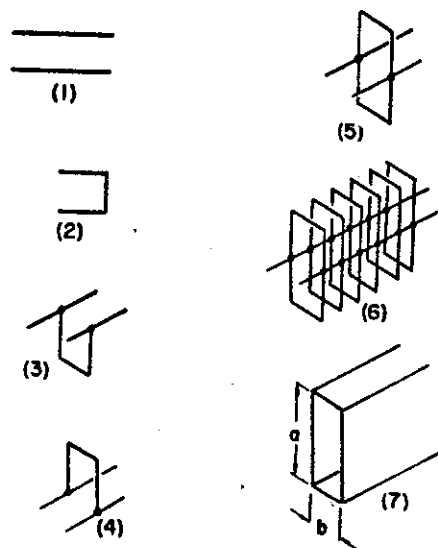


FIGURE 2 - 2

to a thin layer at its surface. The ability of fields to form is limited by the amount of current flow associated with them. Increasing the resistance, decreases the current flow which decreases the magnitude of the fields and decreases the amount of energy transfer. At higher frequencies, the current flow is more on the surface of the conductor thus producing greater resistance. The surface area of the center conductor of a coaxial cable is quite small which gives it a very small current handling capacity.

If the center conductor is removed, the fields are retained and energy will be transferred with less loss. Electromagnetic fields can transfer energy in a line which does not have a center conductor providing that the configuration of the fields is changed to compensate for the missing conductor. If the conductor is removed from a coaxial cable, the remaining hollow tube is a circular waveguide. While such circular waveguide is very useful for special applications, it has the limitation that the direction of polarization of the wave does not remain dependably fixed as the wave moves along the waveguide. The direction of polarization in rectangular waveguide does remain fixed.

Figure 2 - 2 shows the detailed physical concepts of the standard waveguide most commonly used in microwave work. The details are broken into seven parts for easier understanding.

Part 1 illustrates two simple parallel wires or an open line.

Part 2 illustrates a shorted quarter wave line. Here it is to be used as an A. C. insulator even though it is of electrically conductive metal.

Part 3 shows the same shorted quarter-wave line (of Part 2) attached to and below the open line (of Part 1).

Part 4 shows the same type and size of shorted quarter-wave line attached to and above the open line.

Part 5 shows Parts 3 and 4 combined to form a closed metallic loop. The two wire open line of Part 1 can still function as heretofore since the short circuits of the quarter-wave shorted lines are at opposite impedance.

Part 6 shows a large number of similarly developed closed loops.

Part 7 shows an infinite number of closed loops, so many in fact that they became a solid pipe. The exact center of the "a" dimension for the larger side walls corresponds to the two wires shown in Part 1, from the center upward corresponds to quarter-wave A. C. insulators shown in Parts 2 and 4, from the center downward corresponds to quarter-wave A. C. insulators shown in Parts 2 and 3.

Thus, an open line has become a solid pipe. The "a" dimension determines the lowest frequency which can be propagated down the waveguide and still make longitudinal headway. The "b" dimension determines the maximum amount of power which the waveguide can safely handle without flashovers within the waveguide. It affects the characteristic impedance of the waveguide. The "b" dimension must be substantially less (usually a little less than half) than the "a" dimension in order to avoid any possibility of its usurping the latter's function as to cut-off frequency. The field configurations in this rectangular waveguide are shown on the "Chart of Electromagnetic Radiations". It is not necessary to use metallic walls to guide the fields in a waveguide. Fields will reflect when they encounter any substance of different dielectric characteristics than the one in which they are travelling.

The advantages of waveguides over r-f transmission lines are great. Metal conductor losses, dielectric losses, and radiation losses are a minimum.

1. Metal conductor losses - these are essentially I^2R losses. Due to the skin effect in a wire, resistance increases and the heating effect is considerable. This heat dissipates wave energy. Since the conducting area in a waveguide is large compared with an r-f line, resistance is decreased and heating effects are less noticeable.

2. Dielectric losses - these are losses due to heating of the insulation between the conductors. Since there is no center conductor in a waveguide, air is the only substance in contact with the conductor. The dielectric constant of air is small and it follows that the dielectric losses in it are small.

3. We have already seen how radiation losses occur in power lines due to nonconfinement of the fields. In a waveguide, the fields are wholly confined thus eliminating radiation loss.

4. Power handling capabilities of waveguide are greater than those of a coaxial cable of the same diameter. Power is a function of E^2/Z_0 where E is the maximum voltage in the wave and Z_0 is the characteristic impedance of the line. The maximum voltage is limited by the distance between the conductors. In coaxial cable, this distance is only that between the center conductor and the outer conductor; where in waveguide, the distance is the entire diameter.

5. Waveguide is simpler to construct than coaxial cable.

6. Waveguide can stand more physical abuse than coaxial cable.

As with most scientific developments, there are both advantages and disadvantages. The decision of whether to replace an old concept with a new idea rests upon whether the advantages of the new idea outweigh the disadvantages. There is a major disadvantage of waveguide.

Cross-sectional dimensions of a waveguide must be in the order of a half wavelength for it to contain electromagnetic fields properly. If the broad dimension of the waveguide is less than one-half wavelength, energy will not be propagated. There is no upper limit to the frequency that a waveguide transmits. However, if the frequency extends more than fifty percent above this "cut-off" frequency, the waveguide begins to transmit complicated modes that are difficult to measure. When waves are at the frequency of one megacycle, the waveguide has to be about 700 feet wide. Dimensions which waveguides require make them impractical below about 350 megacycles per second. At this frequency, the waveguide has the dimensions of 21.5 x 11.0 inches.

Waveguides transfer electromagnetic waves by containing the electric and magnetic fields and propagating them along the length of the guide. The fields are sinusoidal in configuration, first reaching a maximum in intensity, then a minimum, again a maximum, and again a minimum as the generating source oscillates. The section of the "Chart of Electromagnetic Radiations" labeled "Waveguide Field Configurations" shows a typical waveguide with its TE_{01} mode of energy. A waveguide can be made to support a number of configurations of fields. These are identified by a TE_{nn} number. TE stands for transverse electric, the first number is the number of half-wave patterns on the narrow wall of the waveguide and the second number is the number of half-wave patterns on the broad wall of the waveguide.

There are three methods of exciting a waveguide, by electric fields, magnetic fields, and electromagnetic fields. If a small probe or antenna is placed into a waveguide and fed with radio frequency, r-f signal, current will flow in the probe and set up an electron field about the probe. Positioning this probe at a critical position, determined by its distance from the end of the waveguide, will cause a field of some intensity to be transmitted in the waveguide.

Magnetic field excitation is achieved by introducing a small loop into the waveguide. Having the loop carry a high alternating current, causes a magnetic field to develop about the loop which will expand to fit the waveguide. If the frequency of the current is correct, energy will be coupled from the loop into the waveguide.

For electromagnetic excitation, a horn is placed on the open end of the waveguide to match the impedance of the waveguide to the impedance of air. An electromagnetic wave is allowed to enter this horn. A wave of the correct frequency for the waveguide will then be propagated.

Due to the reciprocity of energy transfer, these three methods are useful for transferring energy in both directions. That is to say, we may both inject and remove energy from a waveguide in these ways.

Tubes for the generation of microwave energy are of the velocity modulation type. In these tubes, a signal is transferred to the electron beam from the control grid. The control voltage speeds up or slows down the velocity of the electrons in their journey from the cathode to the anode.

Let us examine the operation of a typical klystron tube as depicted in Figure 2 - 3. Electrons emitted, due to thermionic emission, from the cathode are attracted by the action of the positive anode and approach it at increasing speed. The anode, being a grid, does not permit the electrons to pass through unhindered. After the electrons pass through it, the anode tends to slow them down and to reattract the electrons back toward its grid structure. Varying the D. C. voltage on the reflector, varies the return time of the electrons to the anode grid structure. The r-f field generated in the cavity by the initial flow of electrons causes subsequent electrons to bunch.

The r-f fields generated are reinforced by the passage of bunched electrons. The r-f energy is coupled out of the resonant cavity into the waveguide by the coupling loop and output antenna.

The size of the cavity is changed by a band which can be tightened around the cavity. Changing the size of the cavity will change its frequency and, by experiment, the optimum cavity size for maximum power output can be determined. Power output of klystrons vary from very small fractions of a watt to better than fifty megawatts.

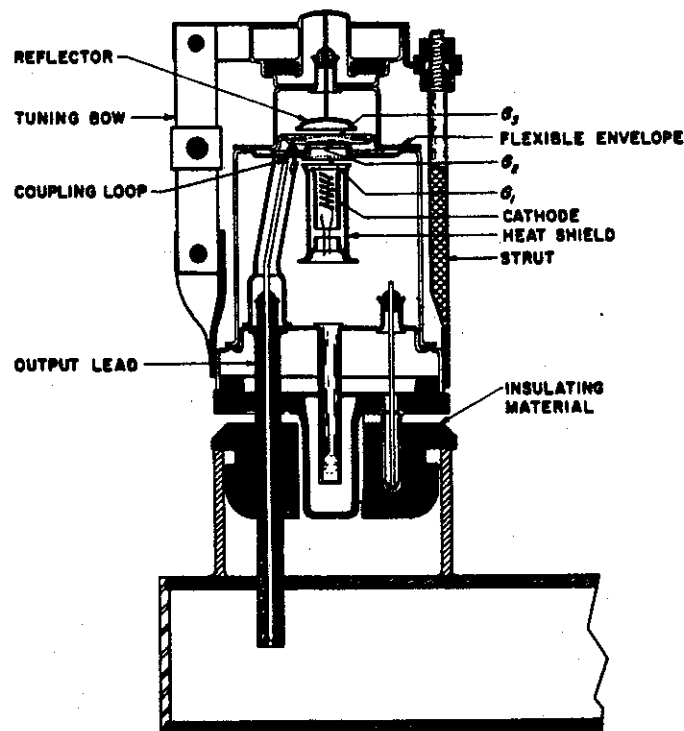
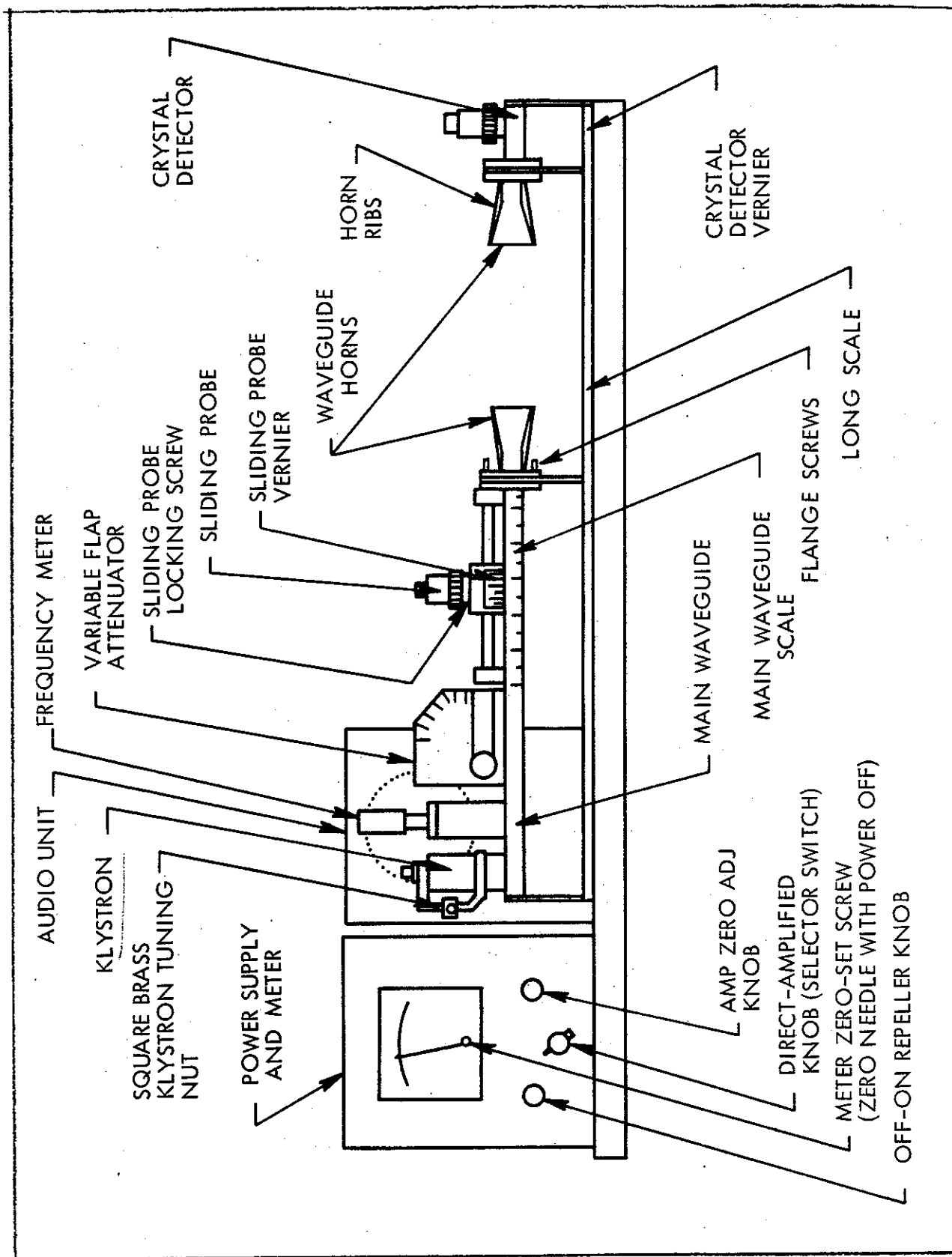


FIGURE 2 - 3



Chapter 3

ED-SET[®] DESCRIPTION

Looking at the Budd-Stanley Ed-Set[®], the following components are noted: The cabinet at the extreme left is the power supply and detection meter combination. The power supply generates the required voltage to cause the operation of the klystron.

A cable transfers the required voltages to the klystron tube, the operation of which we have discussed previously. The microwave energy is transmitted into the waveguide by an antenna attached to the output cavity of the klystron and protruding into the waveguide from the bottom of the tube.

FREQUENCY METER

The frequency of the transmitted signal is measured by the next component which is the frequency meter of cavity wavemeter. Frequency is measured by absorption of the r-f energy which is coupled through a hole in the waveguide into the cavity. The size of the cavity is adjustable by a micrometer screw whose readings are converted into frequency. When the cavity is the correct size for the frequency of the signal, about 25% of the energy is absorbed and a sharp dip is noted in the output power as displayed on the meter.

VARIABLE FLAP ATTENUATOR

A flap attenuator which is used for adjusting the power level in the microwave system is the next component. A microwave attenuator acts like a resistor in a low-frequency electrical circuit. Energy incident upon the attenuator card, causes the card to be heated and to dissipate wave energy. The greater the depth of penetration of the card into the r-f field, the greater the dissipation of energy. Since we are discussing power, the attenuator is calibrated in decibels of attenuation. This attenuation is given by the equation:

$$\text{db} = 10 \log_{10} (P_i/P_o)$$

where P_i is the power input and P_o is the power output.

SLOTTED LINE AND SLIDING PROBE

A slotted line and sliding probe combination is the next component. This component is provided in order to investigate the characteristics of the field in the waveguide. Energy does not radiate through the slot because the slot is narrow enough and the wall thickness of the waveguide is great enough so that the electric field lines of the wave in

the guide will terminate on the sides of the slot, thus confining the field. The slot is in the center of the broad wall so that the maximum field intensity occurs directly beneath it. The probe is a pick-up antenna mounted above the slot. Placing the probe into the r-f energy field causes the microwave diode in the probe to produce a D. C. voltage which is transmitted by a cable and indicated by the meter. As the probe is moved along the slot, the intensity of the field is seen to go from a maximum to a minimum to a maximum in a sinusoidal fashion.

By measuring the distance between any two minima, the wavelength of the signal in the waveguide can be obtained. We can also measure the Voltage Standing Wave Ratio (VSWR) with this component as we shall see in the experiments. VSWR is the square root of the ratio between the maximum voltage of the transmitted and reflected waves in the waveguide. Reflected waves are always undesirable since they cause a decrease in the output power. A perfect transmission line has no reflected waves. However, manufacturing imperfections and the necessity for transmission lines to change their shape and direction (rotating antennas, etc.) cause both mechanical and electrical mismatches to occur which cause reflections of the transmitted signal to travel back along the line. The Voltage Standing Wave Ratio gives us a picture of the standing wave which results from the coincidence of the propagated and reflected waves and thus we can determine how much electrical mismatch there is in the line. Since mismatch is a measure of how much power is lost, it is a very important concept in measuring the efficiency of all microwave structures.

WAVEGUIDE HORN

Waveguide horns are provided in order to match the impedance of the waveguide to that of air. The impedance difference results from the fact that there is a difference between the wavelength in air and the wavelength in the waveguide.

WAVEGUIDE CRYSTAL DETECTOR

A waveguide crystal detector is provided to detect the received power. Its operation is the same as the sliding probe except that the crystal is in a fixed position relative to the waveguide. The resulting D. C. voltage is transmitted to the meter by the coaxial cable.

Microwave diodes (crystal detectors) are solid state devices used for the conversion of r-f energy to D. C. voltage. The r-f energy is useless to a meter. It is therefore converted and rectified by the action of the diode to a D. C. voltage which will register on the meter. The current through a microwave diode is essentially proportional to the square of the potential across the diode, therefore, the meter indication is proportional to the intensity of radiation.

The front panel of the power supply cabinet contains a selector switch which allows the input signal to be either directly indicated or amplified and indicated. Some of the experiments deal with low-power signals which must be brought to a sufficiently high level for detection.

Chapter 4

INITIAL TURN-ON INSTRUCTIONS

These instructions should be followed each time the equipment is put into operation. Each unit has been carefully inspected and electrically tested prior to shipment. If the procedures are followed carefully, the many interesting experiments outlined in the subsequent chapters can be performed easily. Only the finest material and workmanship have gone into this equipment to insure a long and trouble-free life. Every exposed portion of the equipment is grounded to prevent electrical shocks. As a further precaution, do not handle the klystron or the grid cap lead until 60 seconds after turning off the power supply.

1. Read this chapter in its entirety before proceeding to follow any of the instructions contained herein.
2. Carefully unpack all the parts and check them against the illustrated contents in the Appendix.
3. At the extreme left is the power supply and indicating meter. The rear cabinet contains the audio detector. Next to it is the main waveguide, containing, from left to right, the klystron (painted red to indicate that it is thermally hot), the frequency meter, the variable flap attenuator and the sliding probe.

The face of the meter panel contains the control knobs. The left knob is marked "OFF-ON-REPELLER". The "OFF-ON-REPELLER" knob energizes the power supply and varies the voltage supplied to the repeller plate of the klystron tube. The "AMP. ZERO ADJ." knob, which is operative only when the selector switch is in the "AMPLIFIED" position, allows the meter to be zeroed in this position. The "DIRECT-AMPLIFIED" knob, when in the "AMPLIFIED" position, causes the input voltage going to the meter to be amplified. This position is used for low-level signals. In the "DIRECT" position, the input voltage (microwave diode output) is applied directly to the coil of the meter and its presence and magnitude are indicated without any amplification. The majority of the experiments will be carried out in the "DIRECT" position of the selector switch.

In order to aid in the detection of the microwaves, an audio detection circuit has been included. The volume level of this 1000 cycle signal varies directly with the power level as indicated by the meter. A jack is provided, "EXT. MOD", which enables the user to use external modulation when desired. A second jack, "OUTPUT", allows the detected signal to be displayed on an oscilloscope or some other detector.

4. Be sure that the klystron is firmly seated in the klystron tube socket by applying moderate pressure to its upper portion.

5. With the "OFF-ON-REPELLER" knob in the "OFF" position, plug the power supply into a 110V AC outlet. (Use a voltage regulator if one is available. Otherwise, do not use an outlet which is subject to extreme variations in line voltage.)

6. The volume control knob on top of the audio circuit should be on the off position. Place the selector switch in the "DIRECT" position and turn the "OFF-ON-REPELLER" knob clockwise until it clicks. The meter face will light up indicating that the equipment is on. The klystron requires about five minutes to warm up. This warm-up period can be used to set up the rest of the equipment, as outlined in steps 7 through 13.

7. Place the variable flap attenuator at its 30 db, maximum attenuation, position.

8. Place the frequency meter to its maximum closed position by GENTLY turning the micrometer barrel to its maximum clockwise position.

9. Loosen the sliding probe locking screw (located at the left-rear corner of the top of the base plate of the sliding probe) and place the sliding probe at its extreme right hand position on the parallel rails.

10. With the rib-side up, attach one of the waveguide horns, utilizing four of the knurled screws, to the end of the main waveguide. The screws should be finger tight. This horn will be referred to as the transmitting horn.

11. Similarly, attach the other waveguide horn to the crystal detector. This combination will be referred to as the receiver assembly.

12. Attach the plug of the coaxial cable protruding from the back of the power supply to the pin-jack output of the crystal detector of the receiver assembly.

13. Place the receiver assembly in a position, facing the transmitting horn, with its zero vernier line at 16 centimeters on the long scale.

14. Set the variable flap attenuator to read 12 db. SLOWLY turn the "OFF-ON-REPELLER" knob through its entire range noting the various meter indications. When the entire range of the knob has been exhausted, return it to the position which gives the maximum meter reading. This must be done slowly as the correct repeller voltage is quite precise. If too much power is obtained, the meter needle will go off scale (above 100). Reduce the power by slowly adjusting the flap attenuator to a higher D. B. reading to give a meter reading of 50.

15. In order to operate the audio circuitry, tune the klystron for its maximum output as described in Step 14. Turn the "ON-OFF-VOLUME" switch of the audio to its "ON" position and adjust the volume to the desired level. The volume level is controlled by the audio volume control located on the audio circuit cabinet.

If it is desired to use some modulation other than the 1000 cycle signal, connect the external-speaker jack of the modulation source (radio, phonograph or tape recorder) to the audio circuit jack labeled "EXT. MOD." This turns off the 1000 cycle modulation and only the external modulation is transmitted. The connecting lead requires a phono plug on the end which connects to the audio circuit. The volume of the signal can now be controlled by the audio volume control and the external source volume control.

By connecting the "OUTPUT" jack on the audio circuit to the input of an oscilloscope or some other external detector, the transmitted audio can be further seen. The connecting lead requires a pin jack on the end which connects to the audio circuit.

When modulation (internal or external) is placed on the klystron, a drop in meter reading may be observed. This is a characteristic of the circuit and has no adverse effect upon the operation of the Ed-Set.

16. The crystal detector may be mounted on a tripod. The threaded hole in the bottom of the base will fit most standard tripods.

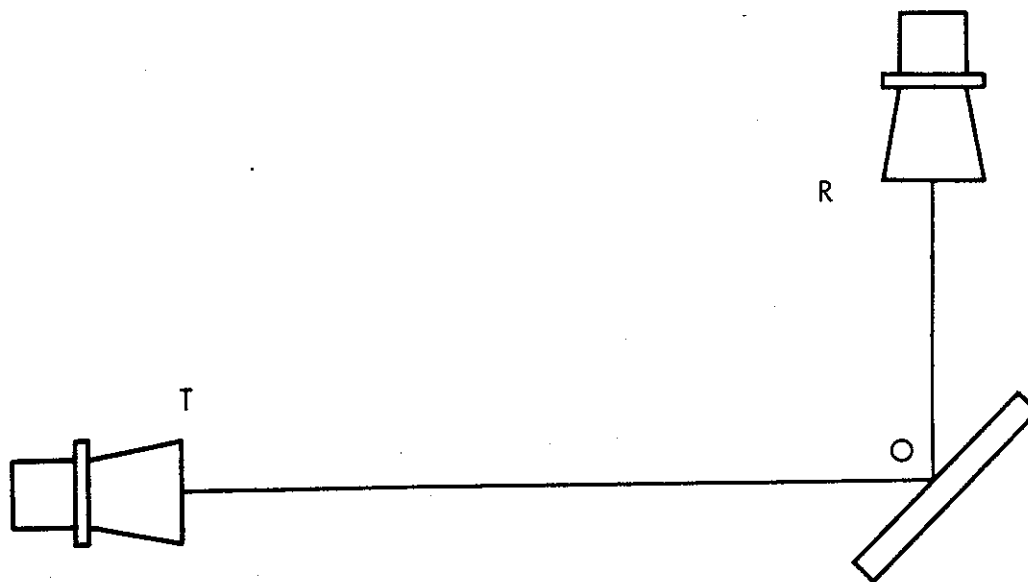


FIGURE 5 - 1

Chapter 5

REFLECTION BY INSULATORS

It is important in the study of microwaves and electromagnetic radiation in general, to know what types of materials will reflect the energy and what types will transmit it. We shall, therefore, study a number of substances in Chapters 5 and 6. We shall find that some materials will reflect all of the energy incident upon themselves and others will reflect a portion of the energy and transmit the rest. Since we shall make use of these various materials in our later experiments, it will be well for the students to make lists of Reflectors, Non-Reflectors, and Partial Reflectors.

Make a list of as many electrical insulators as you can. This list should include such things as wood (wet and dry), cardboard, cork, sponge, plasterboard, cloth, glass, etc. The pieces should be at least as large as the mirror which is included among the components.

1. The equipment must be placed into the ready position as outlined in Chapter 4.
2. Move the receiver assembly along the scale until the zero line on its vernier is opposite the 25 centimeter mark of the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 80.
4. Place the receiver in a position on the board as outlined in Figure 5 - 1. Note decrease in meter reading.
5. Place the test material into a position as shown in Figure 5 - 1. This material can be held in the hand but take care to grip it by its edge so that the hand does not interfere with the reflection.
6. Note the meter reading. This reading should be zero or considerably lower than the reading of 80 for which we set the attenuator in step 3.
7. Try using the mirror.
8. Remove the test material and place the receiver at its initial position next to the 25 centimeter mark on the long scale. (If necessary, readjust the attenuator to obtain a meter reading of 80.)
9. Place the test material between the transmitter and receiver with the plane of the material perpendicular to the direction of propagation of the energy. Try a dry sponge. Try a wet sponge. Place an empty glass in the path. Fill it with water.

After performing this test on all of the items in your list of insulators, what general conclusion can be drawn? Before stating a final general rule about reflectors, let us perform the experiment on electrical conductors found in Chapter 6.

Chapter 6

REFLECTION BY ELECTRICAL CONDUCTORS

$$\begin{array}{r} 3.5 \\ .21 \\ 1.3+ \\ \hline 4.0 \end{array} \quad 5$$

As in Chapter 5, make a list of electrical conductors. This list should include metal sheets, silvered mirrors, screening, etc.

1. The equipment must be placed into the ready position as outlined in Chapter 4.
2. Move the receiver assembly along the long scale until the zero line on its vernier is opposite 25 centimeters on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 80.
4. Place the receiver in a position on the board as outlined in Figure 5 - 1. Note decrease in meter reading.
5. Place the test material into a position as shown in Figure 5 - 1. This material can be held in the hand but take care to grip it by its edge so that the hand doesn't interfere with the reflection. For small objects, such as the mirror, the accessory stand may be used to facilitate holding of the material.
6. Note the increase in meter reading. By adjusting the angle which the plane of the test material makes with the direction of propagation, the meter reading can be optimized. This reading may not be as high as 80 because the path length which the energy now takes, TOR in Figure 5 - 1, may be greater than the path length in Step 3.
7. Remove the test material and place the receiver at its initial position next to the 25 centimeter mark on the long scale. (If necessary, adjust the attenuator to obtain a meter reading of 80).
8. Place the test material between the transmitter and receiver with its plane perpendicular to the direction of propagation. Note the fall in meter reading.
9. If wire screening is used, and the size of the grids is greater than about 1.2 square centimeters, another phenomenon will be observed. Repeat Steps 5, 6, 7, 8 using this large grid wire (chicken wire). It should be observed that this screening will both reflect and transmit the energy. The ratio of this reflection to transmission is determined by the size of the grids and the angle between the plane of the wire and the direction of propagation. This dual nature of the chicken wire makes it quite useful as the half-reflecting surface for the Michelson's Interferometer experiment.

With the results of the experiments in Chapters 5 and 6, we can now postulate a general rule for reflection of microwave energy. Electrical insulators do not reflect microwave energy and electrical conductors do. One outstanding example of an exception to this rule is glass. Once a certain angle, known as the critical angle, is exceeded, glass acts as a good reflector. This is why we can use prisms in optical instruments. There are a number of substances which behave in an analogous manner, clear plastic and water are two common substances.

Once the three lists have been compiled, Reflectors, Non-Reflectors, and Partial Reflectors, test the substances for transparency to light. Are all objects which are transparent to microwaves also transparent to light? Do all microwaves reflectors also reflect light? What is the average wavelength of light? The wavelength of these microwaves is approximately 3.5 centimeters. Does the difference in wavelengths have any effect upon reflection?

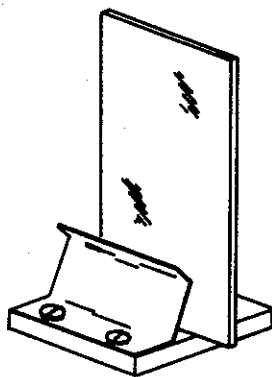


FIGURE 7 - 2

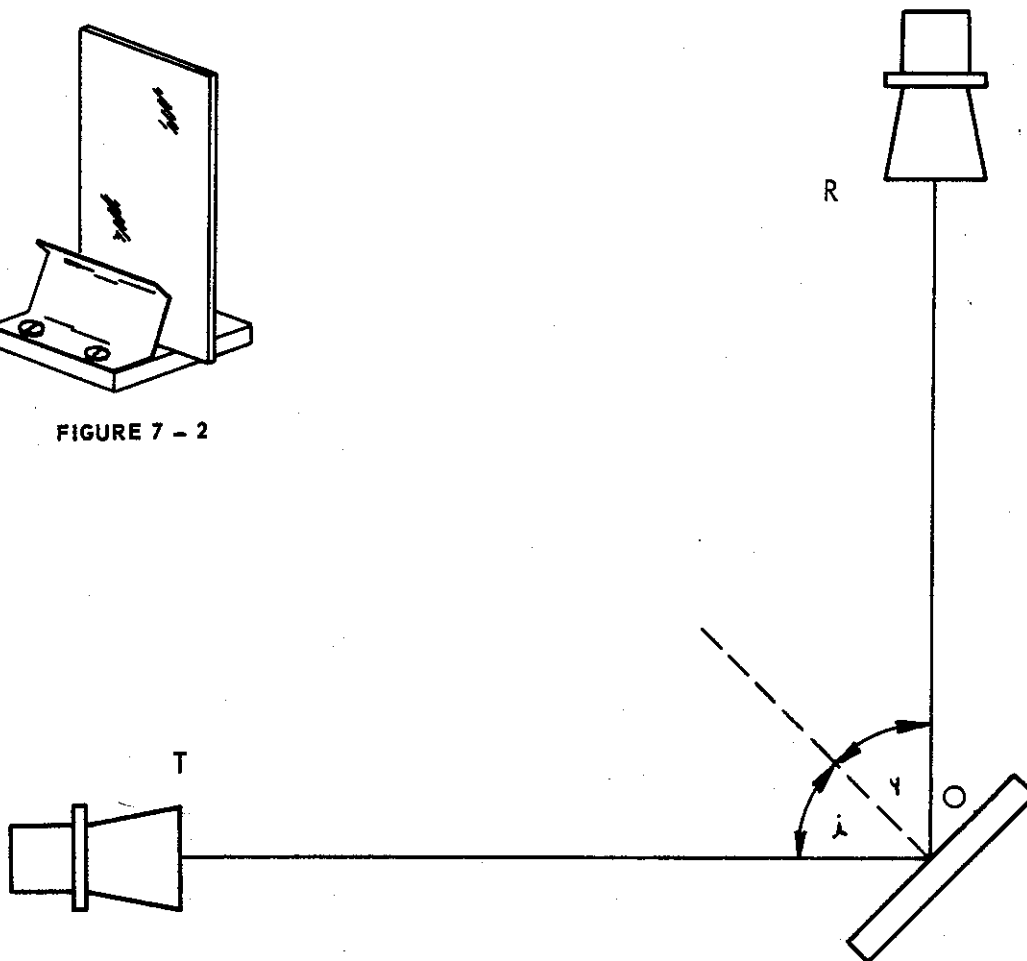


FIGURE 7 - 1

Chapter 7

VERIFICATION OF THE LAW OF REFLECTION

Since, in reflection from plane sheets of substances which reflect both light and microwaves, the waves reflect in a like manner, (180° phase shift or change in direction), we can determine the Law of Reflection using microwaves and assume that all electromagnetic energy will reflect in the same manner.

As illustrated on the bottom left-hand corner of the "Chart of Electromagnetic Radiation", the Law of Reflection states that for electromagnetic energy incident upon a plane reflector, the angle of incidence is equal to the angle of reflection. These angles are measured between the incident ray and the normal to the surface at the point of incidence and the reflected ray and the normal to the surface at the point of reflection.

For this experiment, we shall use the mirror, included in the components, and the accessory stand.

1. The equipment must be placed into the ready position as outlined in Chapter 4.
2. Move the receiver assembly along the long scale until the zero line on its vernier is opposite 25 centimeters on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 80.
4. Insert the mirror vertically into the stand.
5. Place the stand and mirror on the board next to the long scale with the mirror facing the transmitting horn. The edge of the mirror is to be opposite 13 centimeters on the long scale.
6. Place the receiver assembly behind the main waveguide to the right of the transmitting horn. The receiving horn is to face the front of the board with the rib on its upper wall aligned with the edge of the mirror. See Figure 7 - 1.
7. Place a piece of paper on the board. This paper is to be large enough to cover the area from the transmitting horn to the receiving horn and to include the stand and mirror.
8. Starting with the plane of the mirror at a 90° angle with the direction of propagation, slowly turn the stand and mirror toward the receiver assembly.

9. Adjust the mirror angle to give a maximum scale reading on the meter.
10. Draw a line from the center of the transmitting horn parallel to its waveguide and a line from the center of the receiver parallel to its waveguide. Place the center of the mirror at the intersection of these two lines. Rotate the mirror about a vertical axis through the point of intersection until the meter reading is maximized. This can be done if the mirror is extended over one side of the stand so that the stand does not hit the scale as it is rotated. See Figure 7 - 2.
11. Remove the paper and measure the angles of incidence and reflection. These should be approximately equal. If they should be too unequal, repeat steps 1 - 9 taking pains to peak the meter to optimum. Also be sure that the angle between the back plane of the mirror and the direction of propagation is 45° , move the stand and mirror along the scale until the angle approaches 45° .

By experimenting with the placement of the receiver assembly, it can be shown that the angle of incidence is equal to the angle of reflection for any angle of incidence. This principle of reflection will be utilized later in the chapter on Operation of Radar.

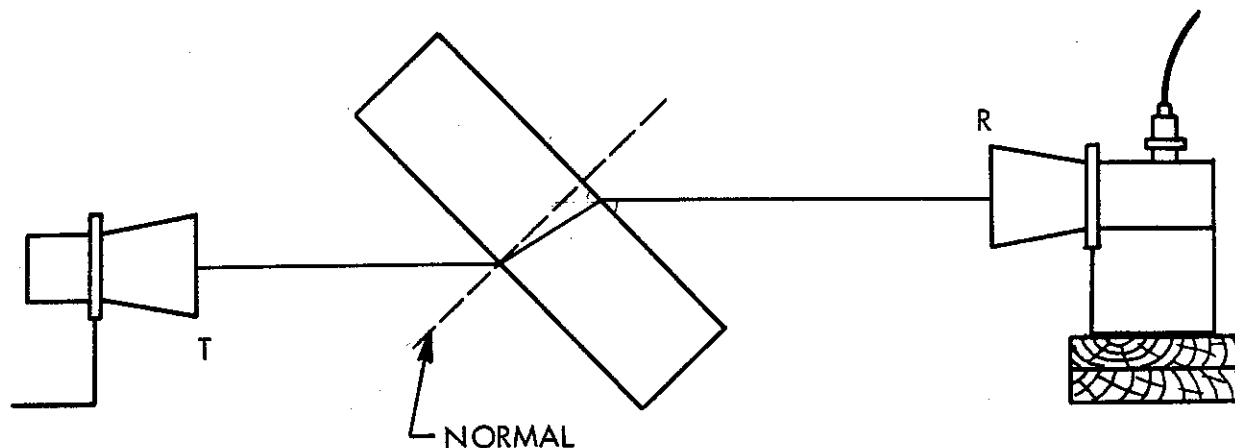


FIGURE 8 - 1

Chapter 8

R E F R A C T I O N

All electromagnetic energy travels at the speed of light. From the "Chart of Electromagnetic Radiation" we see that the speed of light, c , is 2.99793×10^8 m/sec in a vacuum. The difference between the speed in air and that in vacuum is so little that for all practical purposes, we can accept the speed of light in air to be approximately 3×10^8 m/sec.

When light passes from a medium of one optical density to a medium of another optical density, the speed is changed. If the medium into which light passes is of greater optical density than the one in which it was traveling, the speed is decreased. Conversely, if the medium into which light passes is of lesser optical density than the one in which it was traveling, the speed is increased. Thus, if a plane wavefront strikes the boundary between two media of different optical densities at an angle of incidence greater than 0° or less than 90° , the part of the wavefront entering the second medium first will change speeds while the part of the wavefront still in the original medium continues traveling at the same speed. The result is that the wavefront which was originally plane, is now bent. When the entire wavefront has passed into the second medium, the wave is traveling in a direction which is different than the direction in which it was traveling in the original medium. When the second medium is denser than the first, the bending takes place toward the normal to the surface. When the second medium is less dense than the first, the bending takes place away from the normal to the surface.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Move the receiver assembly along the long scale until the zero line on its vernier is opposite 25 centimeters on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 50.
4. Keeping the distance of the receiver assembly approximately the same from the transmitting horn, elevate the receiver assembly about one and one-half to two inches by placing it on a wood block.
5. Note the meter reading in this position.
6. Place the refracting block in front of the transmitting horn in a position so that the large area parallel sides are perpendicular to the board and, also, perpendicular to an imaginary line drawn from the center of the transmitting horn parallel to the long scale. Slowly vary the angle between the refracting block and the board and observe the meter indication. (See Figure 8 - 1.)

In view of the discussion in the beginning of this chapter, how can the behavior of the microwaves be explained? Which way do the microwaves refract when entering the refracting block? From the direction in which the microwaves are bent, what can be concluded about the optical density of the plastic refracting block relative to air? Do microwaves exhibit the same refraction characteristics as light?

Chapter 9

POLARIZATION

The action of a waveguide upon the microwaves which are emitted from the klystron is such that the electric field vector is always perpendicular to the broad walls of the waveguide. Characteristically, therefore, the magnetic field vector is in a plane perpendicular to the electric field vector lines. Since this is always the case, the energy is polarized. Just as polarized light can be analyzed by a tourmaline crystal because of its crystalline structure, polarized microwave energy can be analyzed by a grid whose components are properly shaped. The wavelength of the microwaves is much greater than that of light and, therefore, the analyzer can be a grid with spaces of a tenth wavelength so that the polarizing elements can be clearly seen.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Place the receiver assembly with the zero line of its vernier at 22 centimeters on the long scale.
3. Set the attenuator to obtain a meter reading of 50.
4. Hold the grid in front of the transmitting horn with the slots oriented horizontally with the board. An increase in meter reading may occur at this point. This is because of a small reaction on the source. See the part of the "Chart of Electromagnetic Radiation" on polarization. See Figure 9 - 1.
5. Slowly rotate the grid in the plane of its surface. As the angle made by the slots to the board increases toward 90° , notice the effect on the meter reading. See Figure 9 - 2.
6. The zero meter reading in this position of the analyzer (grid) indicates that the energy is being blocked by the analyzer. Is this energy being absorbed by the analyzer? Is it being reflected?
7. Place the receiver assembly in the position shown in Figure 5 - 1.
8. Hold the analyzer grid with its slots parallel to the board in the position of the test material shown in Figure 5 - 1.
9. Vary the angle between the plane of the analyzer grid and the direction of propagation of the wave. Is there any meter indication?
10. Change the attitude of the analyzer grid so that the slots are perpendicular to the board.
11. Repeat steps 8 - 10 above.

From these results, what happens to the energy when the analyzer blocks it? Is it absorbed? Reflected?

Chapter 10

ATTENUATION

The operation of the attenuator is described in Chapter 2, "Understanding Microwaves". This experiment will familiarize the student with its use.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Set the attenuator to its 30 db position. Record the meter reading.
3. Decrease the attenuation by the steps marked on the attenuator. Record the meter reading at each point. Do these data check with the equation $db = 10 \log_{10} (P_i/P_o)$? You may wish to plot a graph of db against $10 \log_{10} (P_o/P_i)$. When is the most card in the guide? The least? What is the relation between card penetration and meter reading?

FIGURE 9 - 2

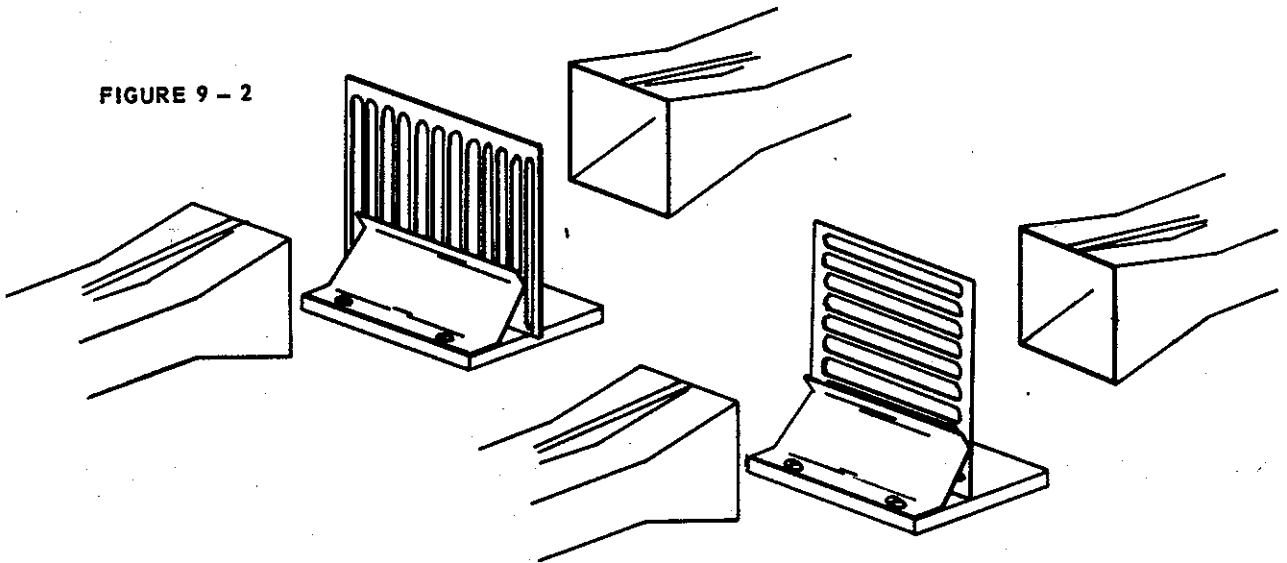


FIGURE 9 - 1

Chapter 11

VSWR MEASUREMENT

The purpose of VSWR Measurement is described in Chapter 2 "Understanding Microwaves".

1. The equipment must be placed into the ready condition as outlined in Chapter 4 with the exception of connecting the plug on the coaxial cable to the output pin-jack of the sliding probe.

2. We will use the signal amplifier for this step. Place the "DIRECT-AMPLIFIED" switch on the front panel of the power supply to its "AMPLIFIED" position and place the flap attenuator to its maximum attenuation position (30db). Using the "AMP. ZERO ADJ." knob, adjust the meter to read zero. Adjust the flap attenuator to obtain a meter reading of 60.

3. Start at the extreme right end of the slotted line and slide the probe slowly along its rails noting the deflections of the meter. If a sufficient meter deflection is not obtained, readjust the flap attenuator to obtain a maximum meter reading of 80.

4. Record a maximum meter reading and the next minimum reading.

5. Using these values, calculate the VSWR with the equation

$$VSWR = \sqrt{\frac{E_{max}}{E_{min}}}$$

6. If the mirror were placed directly over the opening of the transmitting horn, what would you expect the voltage standing wave ratio to be? Verify your expectation by placing the mirror over the transmitting horn opening and repeating steps 3 - 5.

The existence of the standing wave is an indication of interference between the transmitted and reflected waves as shown on the "Chart of Electromagnetic Radiation".

Chapter 12

TRANSMISSION IN RECTANGULAR WAVEGUIDE

Since waveguides play such an important role in microwave, it is worthwhile to understand something about transmission of microwave energy through a waveguide. Therefore, this chapter and the next five will deal with characteristics of rectangular and circular waveguides.

In Chapter 2, "Understanding Microwaves", the construction of a rectangular waveguide is explained. The analogy between transmission in a waveguide and transmission in a parallel, two-wire transmission line is important. Once the concept of energy transfer by fields, rather than currents or voltages, is understood, the student will easily be able to continue on to more sophisticated studies in microwaves.

The configuration of the fields in a rectangular waveguide is shown on the "Chart of Electromagnetic Radiation". The lines of electric force, and hence the electric field, are always perpendicular to the broad wall of the waveguide. In order for the field to be maintained, there can be no portion of the electric field parallel to the broad wall of the waveguide. The maximum intensity of the electric field is at the center of the broad wall of the waveguide and decreases sinusoidally toward the outer edges of the broad wall.

The magnetic field is always contained in a plane which is perpendicular to the narrow wall and parallel to the broad wall. The plane extends along the direction of propagation in the waveguide. In order for the field to be maintained, there can be no portion of the magnetic field perpendicular to the broad wall. The magnetic field intensity is maximum at the outer edges of the broad wall and decreases to zero at the center of the waveguide.

The power waveform which results from the combination of the waveforms of current and voltage, according to the equation $P = IV$, is shown in Figure 22 - 1 in Chapter 22, "Frequency Measurement and Theory". From this, it is seen that power transfer is accomplished in a sinusoidal fashion. It is clearly demonstrated that efficient power transfer is possible because the waveguide confines the fields.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Position the receiver assembly so that the zero of its vernier falls at the 24 centimeter mark on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 20. Figure 12 - 1 shows the radiation pattern of the transmitting horn when the equipment is placed in this configuration.

4. Place the rectangular waveguide which is included with the components between the transmitting and receiving horns. See Figure 12 - 2. The waveguide piece should be positioned so that it acts as an extension of the main waveguide with its broad and narrow walls in the same planes as the broad and narrow walls of the main waveguide and the crystal detector waveguide. Note the meter reading when the waveguide piece is held in this manner. The meter reading can be maximized by varying slightly the position of the piece of waveguide. What conclusions about the action of the waveguide upon the wave can be drawn from the experiment?

5. On a sheet of paper, make outline drawings of the set-up as it is now arranged. Using different colors for different waveforms, (voltage, current and power), show the waveforms within the waveguide.

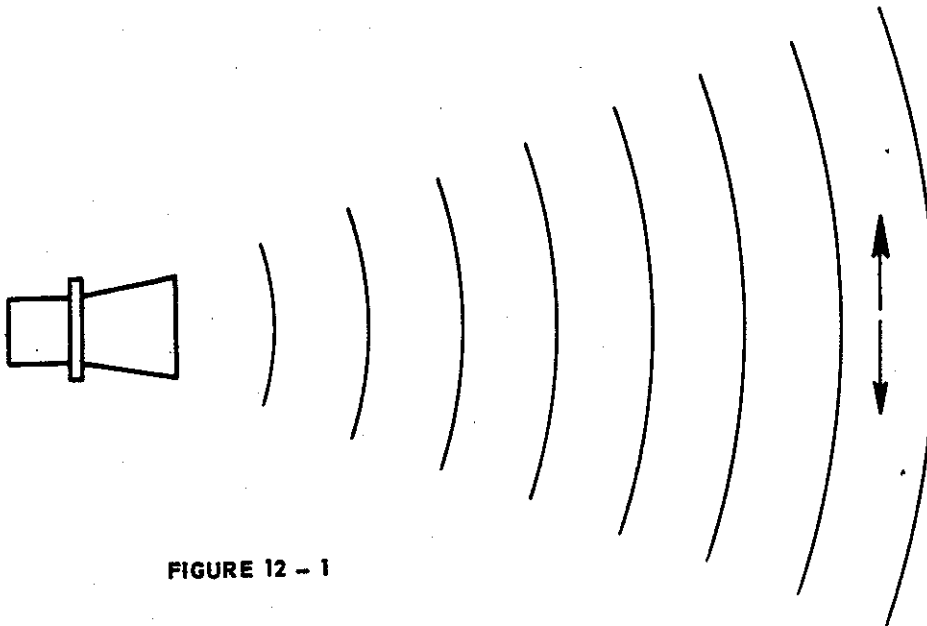


FIGURE 12 - 1

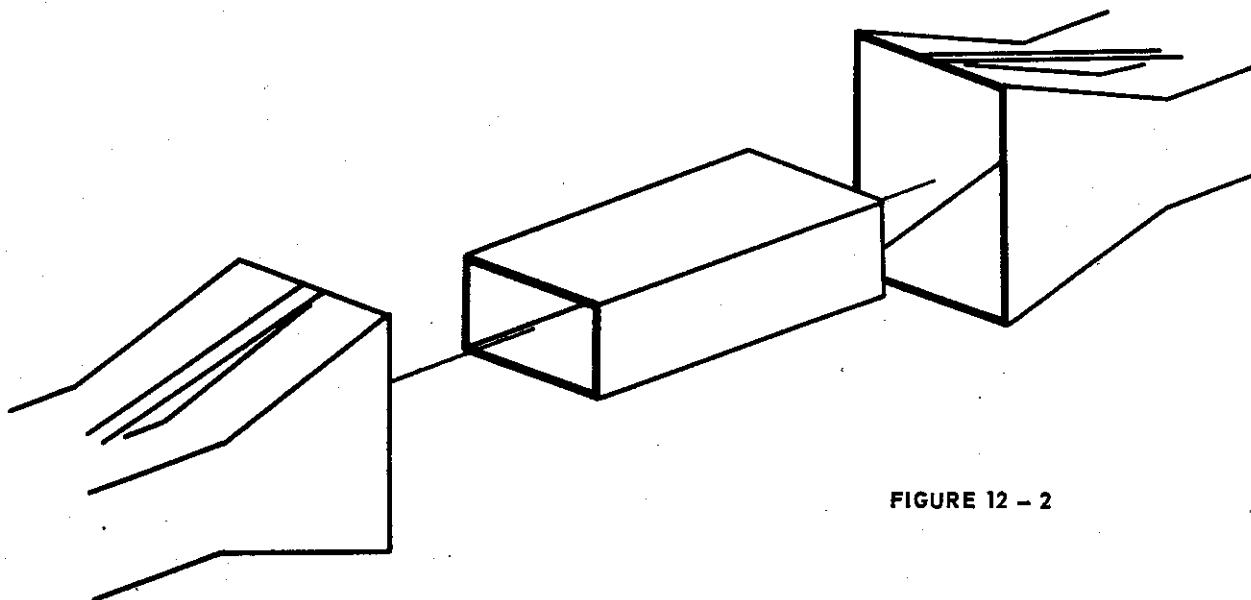


FIGURE 12 - 2

Chapter 13

CUT-OFF IN RECTANGULAR WAVEGUIDE

Since each wave has its characteristic wavelength, the dimension of size can be used in describing the wave. With a definite size for each wave, it would follow that waves of large size cannot "fit" into areas meant for waves of smaller size. This is a simple way of viewing the fact that waveguide will support oscillations of one frequency while they will not support oscillations of another frequency.

Therefore, size of waveguide is quite critical. There is a definite size relationship of waveguide to wavelength which must be met. If the broad wall of the rectangular waveguide is designated as "a" and the narrow wall designated as "b", the following size relationships are generally the case for transfer of energy.

$$a \cong 0.6 \lambda$$

$$b \cong 0.3 \lambda$$

The fact that we must say that the "a" dimension is approximately equal to 0.6λ and the "b" dimension is approximately equal to 0.3λ is shown when we tune the klystron for a different frequency. Remember that a different frequency has a different wavelength. Therefore, these values are only approximate.

1. The equipment must be placed into the ready condition as outlined in Chapter 4 except that the transmitting and receiving horns are to be removed.
2. Position the receiver assembly so that the zero of its vernier falls at the 12.5 centimeter mark on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 40.
4. Insert the piece of rectangular waveguide between the transmitter and receiver. Note the meter reading. If the meter should read above 100, increase the attenuation with the variable flap attenuator to obtain a meter reading of 90.
5. Construct an imaginary line through the long axis of the waveguide (direction of transmission). Slowly rotate the waveguide about this axis through a 90° angle. When this rotation is accomplished, the narrow walls of the piece of waveguide will be in the planes of the broad walls of the main waveguide line. Note the meter reading as the rotation takes place. What conclusions can be drawn?

Chapter 14

ELECTROMAGNETIC FIELD CONFIGURATION IN RECTANGULAR WAVEGUIDE

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Place the attenuator-phase shifter combination component into the accessory stand with the phase shifter end held in the clamp (attenuator up).
3. Place the receiver assembly at a position, facing the transmitting horn, with the zero mark of its vernier at 21 centimeters on the long scale.
4. Place the attenuator and accessory stand against the long scale between the transmitting and receiving horns with the tapered end of the attenuator card facing the transmitting horn. See Figure 14 - 1.
5. Slide the accessory stand along the long scale toward the transmitting horn. The attenuator card will enter the transmitting horn. Slide the accessory stand until the white support rising from the accessory stand touches the lip of the transmitter horn. This causes the attenuator card to be positioned slightly off center of the broad wall of the waveguide.
6. Taking care not to interrupt the r-f field with the hand, slowly slide the accessory stand (pushing it by the base) across the broad wall of the waveguide until the card touches the far narrow wall of the waveguide.
7. As the card crosses the waveguide, notice the meter. The reading will go from a relative maximum at the start, to a minimum at the center of the waveguide, to a maximum at the far narrow wall.

The configuration of fields in waveguide are shown on the "Chart of Electromagnetic Radiation". Looking at the upper left-hand picture in the "Waveguide Field Configurations" sections, one can see the electric field vectors. As the attenuator card approaches the center of the waveguide, the concentration of the field is greater and there is greater attenuation.

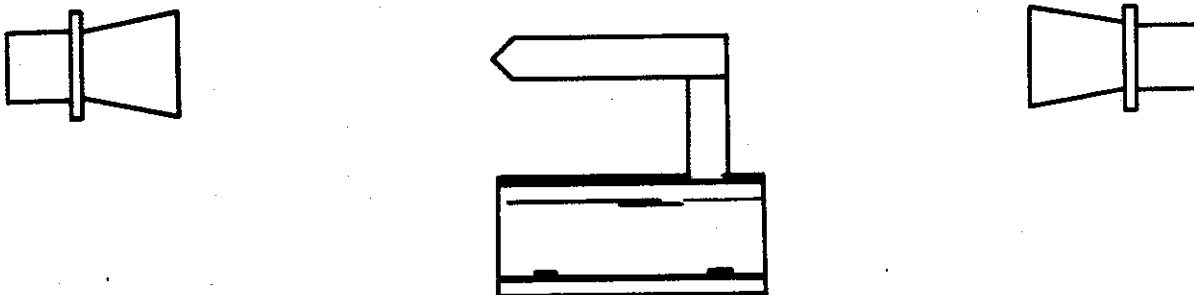


FIGURE 14 - 1

Chapter 15

TRANSMISSION IN CIRCULAR WAVEGUIDE

Microwaves can be transferred through a cylindrical tube just as well as through a rectangular tube.

Remember that the fields travelling through rectangular waveguide are located in certain relative positions. This is also the case in circular waveguide. A basic mode of propagation in circular waveguide is the TE_{11} mode. Figure 15 - 1 shows the vector diagram of this mode.

The arrows represent the lines of force of the electric field and the dots and crosses represent the lines of force of the magnetic field. It is evident, from the diagram, that maximum electric field occurs at the center of the circular waveguide (here, the vectors are more condensed) and the magnetic field is maximum at the perimeter of the waveguide (the location of most dots and crosses). Just as in rectangular waveguide, circular waveguide promotes efficient transfer of energy by confining the fields.

It must be remembered, when looking at a vector diagram of the fields in a waveguide, that this is merely an instantaneous picture of the configuration. In the next half cycle, the fields will have reversed in direction.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Position the receiver assembly so that the zero of its vernier falls at the 24 centimeter mark on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 20. Figure 12 - 1 shows the radiation pattern of the transmitting horn when the equipment is placed in this configuration.
4. Insert the piece of large diameter circular waveguide between the transmitting and receiving horns and observe the meter reading. Does this waveguide increase the efficiency of transfer of the energy? How is the circular waveguide excited?

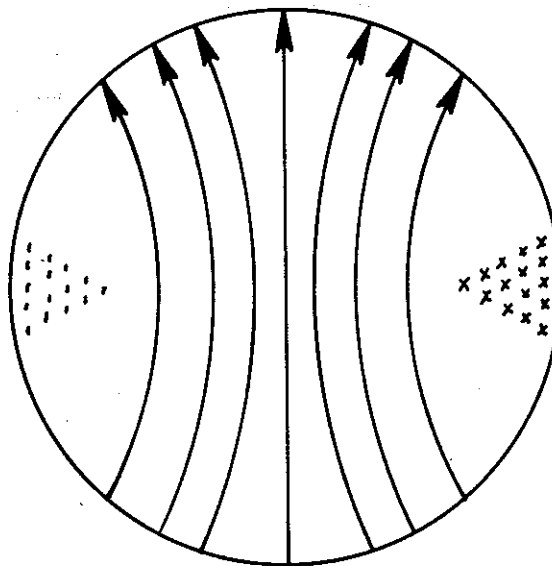


FIGURE 15 - 1

Chapter 16

CUT-OFF IN CIRCULAR WAVEGUIDE

The size of the waveguide is as critical for circular waveguide as it is for rectangular waveguide. While there are two determining dimensions for rectangular waveguide, there is only one for circular waveguide. Since the deciding parameter for the size of a circle is its diameter, one might feel that the diameter of the circular waveguide is the critical dimension. This is, in fact, the case. For best transfer, the diameter of the waveguide should be approximately one wavelength long or larger. Again, as in the case of rectangular waveguide, the size is only approximate.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Position the receiver assembly so that the zero of its vernier falls at the 24 centimeter mark on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 20. Figure 12 - 1 shows the radiation pattern of the transmitting horn when the equipment is placed in this configuration.
4. Place the piece of large diameter circular waveguide between the two horns. Note the meter reading. Figure 16 - 1.
5. Replace the large diameter piece with the small diameter circular waveguide. What does the meter read now? What conclusions can be drawn?

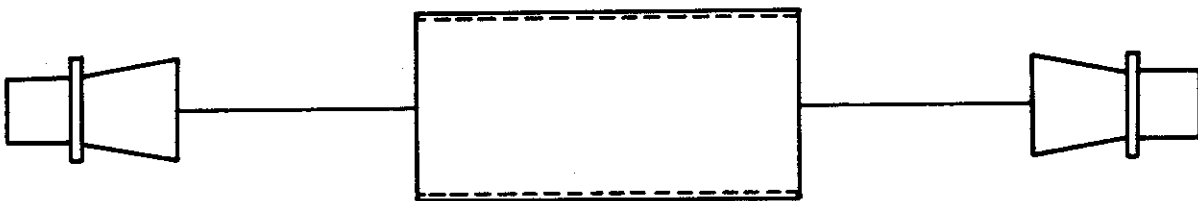
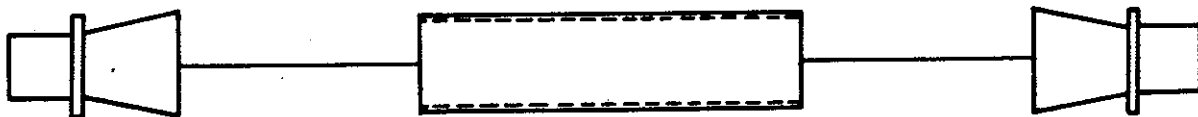


FIGURE 16 - 1



Chapter 17

TRANSMISSION IN DIELECTRIC WAVEGUIDE

If light shines into the end of a lucite rod, no matter which way the rod is bent, provided it is not bent too sharply, the light will transmit through the rod and shine from the other end. Thus, light, which is electromagnetic in nature, is transmitted through the lucite. We shall see if microwaves can also be transmitted through lucite.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Position the receiver assembly so that the zero of its vernier falls at the 24 centimeter mark on the long scale.
3. Adjust the variable flap attenuator to obtain a meter reading of 60.
4. Remove the horns and place the zero of the receiver vernier at 12.5 Place the red lucite waveguide between transmitter and receiver with its axis along the line of transmission. Observe the meter reading. Is it as great as for hollow circular waveguide? Why doesn't the energy come out the sides? What conclusions can be drawn concerning transfer in rectangular, circular and dielectric waveguide?

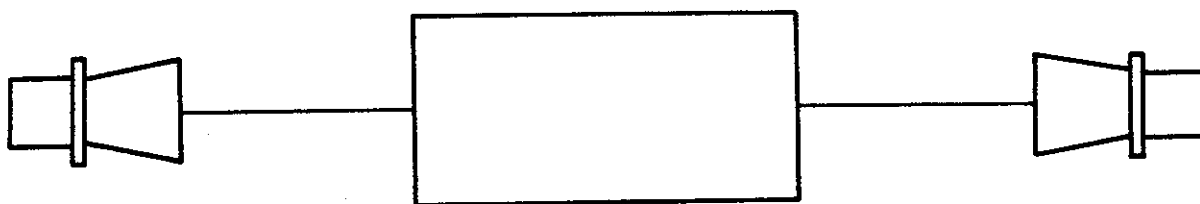


FIGURE 17 - 1

Chapter 18

CHANGING DIRECTION OF TRANSMISSION PATH

Many times it is essential to change the direction of a waveguide system without a corresponding change in polarization. This can be accomplished by bending the axis of the waveguide. In order not to introduce too much reflection into the waveguide system when using a bend, a restriction is placed upon its physical characteristics. The radius of the bend must be greater than two wavelengths of the microwaves which travel through the bend.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Disconnect the transmitting horn.
3. Take the waveguide bend. Note that the holes of one flange are threaded and that the holes in the other flange are not threaded. Connect the unthreaded flange to the main waveguide line so that it bends toward the back of the board. The broad and narrow walls of the bend must be coincident with the broad and narrow walls of the main waveguide line. See Figure 18 - 1.
4. Connect the transmitting horn (rib up) to the open end of the bend with its broad and narrow walls coincident with those of the bend.
5. Place the variable flap attenuator to its maximum attenuation position (30db).
6. Place the receiver assembly about two inches in front of the transmitting horn so that the horns are facing each other at their open ends.
7. Decrease the attenuation with the variable flap attenuator to obtain a meter reading of 50.
8. In order to investigate the reflections in the system due to the bend, remove the receiver assembly and follow the procedure for measuring VSWR found in Chapter 11, "VSWR Measurement".

Perform the VSWR measurement first with the bend attached to the main waveguide line and then with the bend off. Compare the results.

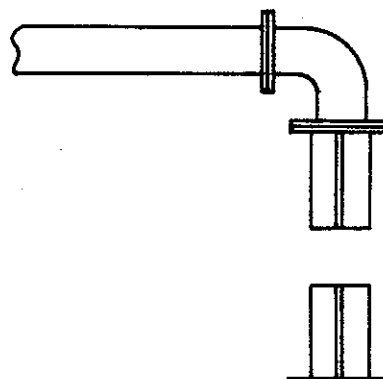
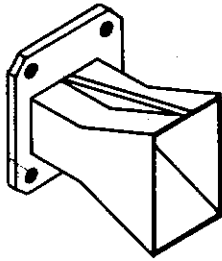


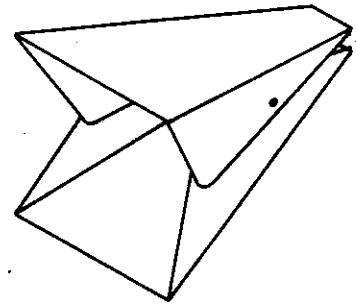
FIGURE 18 - 1

Chapter 19

GAIN HORNS



GAIN HORN



HIGH-GAIN HORN

The Microwave-Optics Ed-Set is equipped with two types of gain horns. These are the small waveguide horns which you have been using and the large High-Gain horns. These both have different electrical characteristics which are direct functions of the physical size of the horns. The aperture of the flared end and the angle which the sides make with each other (if the plane of one side is extended to meet the extended plane of the other side) are the two deciding factors. One can surmise by looking at the horns that the large High-Gain horn have more gain than the small waveguide horns. These horns have been electrically measured and the gains calculated. For the small waveguide horn, the gain is approximately 8 db. For the High-Gain horn, the gain is approximately 22 db. Therefore, we should be able to transmit and receive over much greater distances using the large High-Gain horns than is possible using the smaller horns. This will be demonstrated in the next chapter.

Gain horns provide an impedance match between the impedance of free space (external to the waveguide) and the impedance of the waveguide. The flare of the horn allows the wavefront to undergo a gradual expansion. If the energy went suddenly from the confines of the waveguide into free space, there would be a great deal of reflection from the end of the waveguide and a high voltage standing wave ratio would occur. The larger size horns provide greater directivity and increased received signal strength or gain.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Disconnect the coaxial cable from the receiver assembly and remove the receiver assembly from the board.
3. Disconnect the transmitting horn.
4. Place the variable flap attenuator to its maximum attenuation position (30 db).
5. Place the selector switch, located on the front panel of the power supply, at its "AMPLIFIED" position.
6. Using the "AMP. ZERO ADJ." knob, obtain a meter reading of zero. Do not touch this knob for the balance of the experiment unless you think that the amplifier has drifted. The amplifier can be checked for drift by placing the variable flap attenuator to its maximum attenuation position (30 db). If the meter reads anything but zero, the amplifier has drifted. If this is the case, repeat steps 4 and 6.

7. Connect the coaxial cable to the output on top of the sliding probe.
8. Decrease the attenuation, using the variable flap attenuator, to obtain a meter reading of 20. If, with all attenuation out, a reading of 20 on the meter is unattainable, loosen the locking screw on the sliding probe and move the probe to its left until a maximum reading is obtained. The minimum attenuation should be at least 6 db to protect the klystron from reflected power.
9. Using the procedure outlined in Chapter 11, "VSWR Measurement", calculate the VSWR of the line. Record this reading.
10. Attach the transmitting horn to the main waveguide so that its broad and narrow walls are coincident with those of the main waveguide line.
11. Repeat step 9. What are your results as far as amount of mismatch (high mismatch gives high VSWR) with the horn and without the horn?
12. Place the selector switch on the front panel of the power supply to its "DIRECT" position.
13. Place the variable flap attenuator at its 30 db position.
14. Remove the receiving horn from the receiver assembly and the transmitting horn from the main waveguide line.
15. Place the waveguide crystal detector on the board with the zero line of its vernier at the 19 centimeter mark on the long scale.
16. Connect the coaxial cable to the output on the crystal detector.
17. Decrease the attenuation by placing the variable flap attenuator at its 6 db position. Observe and record the meter reading.
18. Place the variable flap attenuator at its 30 db position.
19. Connect the receiving horn to the waveguide crystal detector so that its broad and narrow walls are coincident with those of the waveguide crystal detector.
20. Decrease the attenuation slowly, observing what amount of attenuation is necessary to repeat the meter reading obtained without the receiving horn. Record this attenuation reading.
21. Place the variable flap attenuator at its 30 db position.
22. Connect the transmitting horn to the main waveguide line so that its broad and narrow walls are coincident with those of the main waveguide line.
23. Repeat step 20.

Reviewing the data obtained through the performance of the experiment, what conclusions can be drawn concerning the electrical characteristics of gain horns?

Chapter 20

USE OF GAIN HORNS IN LONG-RANGE TRANSMISSION

The intensity of electromagnetic radiation decreases as the square of the distance from the source to the receiver. Therefore, as we move away from the transmitter, the detected signal strength decreases quite rapidly. This situation could be solved by building bigger and more powerful transmitters. There are practical limits to the size and power of klystrons. These include cost, difficulty of handling large tubes and heat dissipation. There are presently in operation klystron transmitters whose powers are of the order of megawatts (millions of watts). These are necessary when the signal must be bounced from some remote object and detected at the receiver located near the transmitter.

Another solution is possible. The use of high-gain horns and antennas at the transmitter and receiver will increase the effective signal strength. Much effort and money is spent on developing newer and higher gain antennas. This experiment will show the effect of high gain horns (antennas).

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Connect the waveguide bend to the main waveguide line so that the main waveguide line is bent to face outward from the front of the board.
3. Connect the transmitting horn to the end of the waveguide bend so that its broad and narrow walls are coincident with those of the waveguide, rib up.
4. Decrease the attenuation by placing the variable flap attenuator at its 3 db position.
5. Move the receiver assembly away from the transmitting horn keeping the receiving horn in the line of transmission of the transmitting horn. Try this with the audio on. The receiver assembly should be hand held or attached to a tripod.
6. When the meter reading has been decreased to 10, measure the distance, D , from the flared end of the receiving horn to the flared end of the transmitting horn. See Figure 20-2. Record this distance.
7.
 - a. Place the variable flap attenuator to its maximum attenuation position (30 db).
 - b. Place the selector switch, located on the front panel of the power supply, at its "AMPLIFIED" position.
 - c. Using the "AMP. ZERO ADJ." knob, obtain a meter reading of zero. Do not touch this knob for the balance of the experiment unless you think that the amplifier has drifted. The amplifier can be checked for drift by placing the variable flap attenuator

to its maximum attenuation position (30 db). If the meter reads anything but zero, the amplifier has drifted. If this is the case, repeat step 7c. The amplifier has a gain of four which will increase the transmission path length.

8. Repeat steps 4, 5, 6.

9. Connect a High-Gain horn to the receiving horn. In order to attach the High-Gain horn, hold the larger end in your hands and squeeze slightly. This will cause the smaller end to open. Place the smaller end over the waveguide horn. Release the pressure on the larger end causing the smaller end to clamp tightly to the waveguide horn. See Figure 21 - 2.

10. Repeat steps 4, 5, 6.

11. Connect the other High-Gain horn to the transmitting horn in the same manner as step 9.

12. Repeat steps 4, 5, and 6. What conclusions can be drawn about the gain of the various horns?

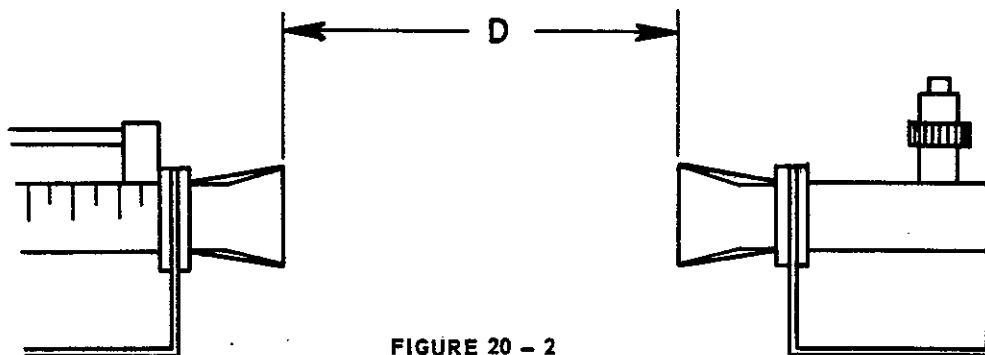


FIGURE 20 - 2

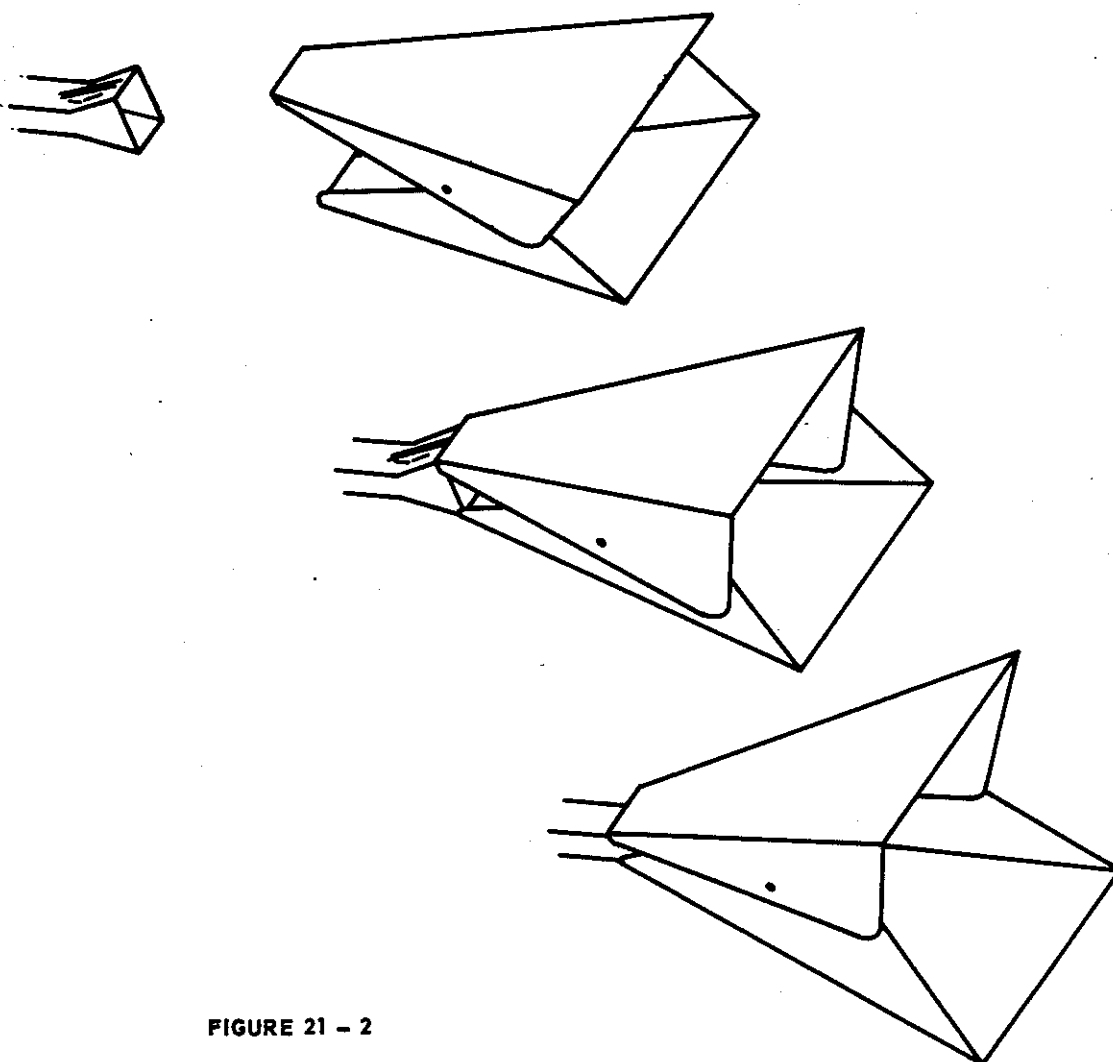


FIGURE 21 - 2

Chapter 21

GAIN HORN PATTERNS

For every gain horn, there exists what is known as a horn pattern. This pattern is the intensity of the signal plotted against the angle of deviation from the line of sight. (Line of sight is a straight line drawn perpendicular to the plane of the flared end of the gain horn.) In many applications, this pattern is quite critical. If it is too wide or too narrow, the operation may be severely hindered. We shall plot the gain horn pattern for the High-Gain horns.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Attach the waveguide bend to the main waveguide line so that the main waveguide line is bent to face outward from the front of the board.
3. Connect the transmitting horn to the output end of the bend so that its broad and narrow walls are coincident with those of the waveguide.
4. Attach the receiver assembly to a tripod.
5. Attach the High-Gain horns, one each, to the transmitting and receiving horns.
See Figure 21 - 2, page 37.
6. At a distance of about two feet, align the transmitting and receiving horns in height and line of sight.
7. Adjust the variable flap attenuator to obtain a meter reading of 80.
8. Vary the horizontal angle of the receiver assembly slightly to maximize the meter reading. This is to be done by panning the tripod head. This point of maximum meter reading we will call 0° . Record the meter reading.
9. Turn the receiver assembly through 20° taking meter readings at 1° increments. Do this for both directions from the 0° mark. Record the readings and their corresponding angles.
10. On polar graph paper, plot the High-Gain horn pattern.

Chapter 22

FREQUENCY MEASUREMENT AND THEORY

In the case of visible light, frequency is rather easily determined by observing the color of the light. Red is the lowest frequency of the visible spectrum and violet is the highest. In the case of the rest of the electromagnetic spectrum, the beam can not be seen as we see light. Therefore, means must be devised to determine the frequency of the wave.

An observation of electromagnetics is that one particular size of cavity will resonate to a particular frequency and its harmonics. When an electromagnetic wave begins, at zero voltage, to build up toward its maximum, its electric field causes the electrons to move according to the laws of electrostatics. At its maximum, a condensation of electrons has occurred at one point on the wall of the cavity. As the voltage begins to fall, in the second quarter of the cycle, the electrons do not experience as great a field strength and begin to move apart due to the electrostatic forces among them. As the wave reaches zero voltage, the electron condensation is again in its initial position. This procedure repeats twice per cycle as the voltage form is rectified.

Figure 22 - 1 shows the voltage, current and resulting power waveforms. It is obvious that there are two voltage peaks in each wavelength. Thus, the described movement of the electrons occurs twice per cycle.

It takes a finite amount of time for the condensation of electrons to travel the distance shown in Figure 22 - 2. In order to sustain an oscillation, the point of high electron density must travel only as far as one-half the distance around the cavity. This is the condition required for maximum resonance. Therefore, since the time of travel of the point of high electron density is determined by the frequency, only one size of the cavity will support the oscillation. We should note that although electrons drift slowly in metals under potential differences, the positions of electron concentrations move with nearly the speed of light. When this oscillation occurs, maximum energy is coupled into the cavity and a decrease in the output power is noted on the meter.

Frequency meters are calibrated according to size. The micrometer barrel reading is converted directly into frequency by the chart in Appendix I. This chart of frequency vs. micrometer barrel reading was prepared by turning the cavity of the reflex klystron to the lowest frequency at which it will oscillate. At this point, the frequency meter on the Ed-Set[®] was tuned until it was in the state of maximum electromagnetic oscillation (maximum meter dip). The micrometer barrel reading of the Ed-Set[®] frequency was noted and recorded at this point. The Ed-Set[®] frequency meter was then detuned and a standard, calibrated, frequency meter was placed into the waveguide line and tuned to its state of maximum oscillation. The frequency indicated by this standard meter

was obtained and thus the frequency corresponding to this one micrometer barrel reading of the Ed-Set® frequency meter was obtained. As an additional calibration, the free-space wavelength was calculated and converted into frequency using the equation: $c = f \lambda$ where c is the speed of light, f is the unknown frequency, and λ (lambda) is the free-space wavelength. This procedure was repeated across the entire frequency range of the klystron at 20 distinct points and the results were plotted and are shown on the graph.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Starting with the micrometer barrel of the frequency meter in its maximum clockwise position (reading zero), turn the micrometer counter-clockwise until a sharp dip is noticed on the indicating meter.
3. At this point, adjust the barrel of the frequency meter very carefully to obtain the maximum dip. The cavity is now adjusted to the exact size corresponding to the frequency of oscillation. At this size, the cavity will resonate causing some of the transmitted energy to be absorbed by the cavity and the resulting dip in the output level.
4. Convert the micrometer dial reading to frequency by using the Frequency Meter Calibration Chart found in Appendix I.

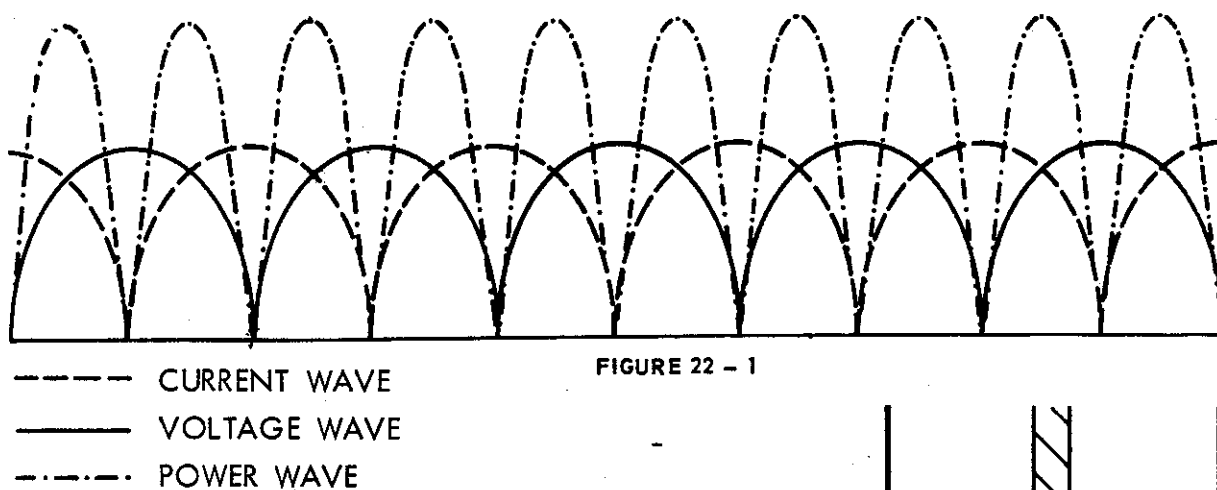
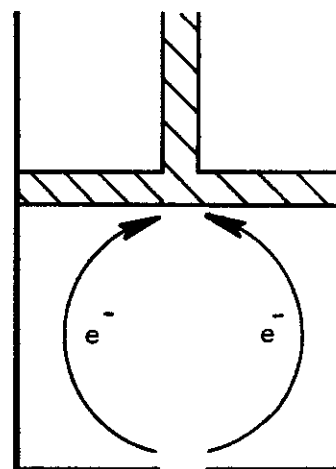


FIGURE 22 - 2



Chapter 23

TUNING THE KLYSTRON

The operation of the klystron tube is explained in Chapter 2. It is there stated that the cavity in the top of the klystron is excited into electromagnetic resonance and the resulting radio-frequency (r-f) energy is coupled into the waveguide by the antenna. Now that the tuneable cavity frequency meter has been studied, we can use the same explanation for the operation of the resonant cavity in the klystron. The size of the klystron cavity is changed by a band around the cavity. By turning the klystron tuning key, we cause the band to exert more or less pressure on the cavity, thus changing its size.

1. Repeat steps 1 - 4 of Chapter 22, "Frequency Measurement and Theory".
2. After determining the frequency of the klystron at this position, change the frequency of the klystron by turning the klystron tuning key 90° in either direction. Re-adjust the repeller voltage by turning the repeller knob on the front panel of the power supply until a maximum indication is obtained on the meter.
3. Repeat steps 1 - 4 of Chapter 22, "Frequency Measurement and Theory".

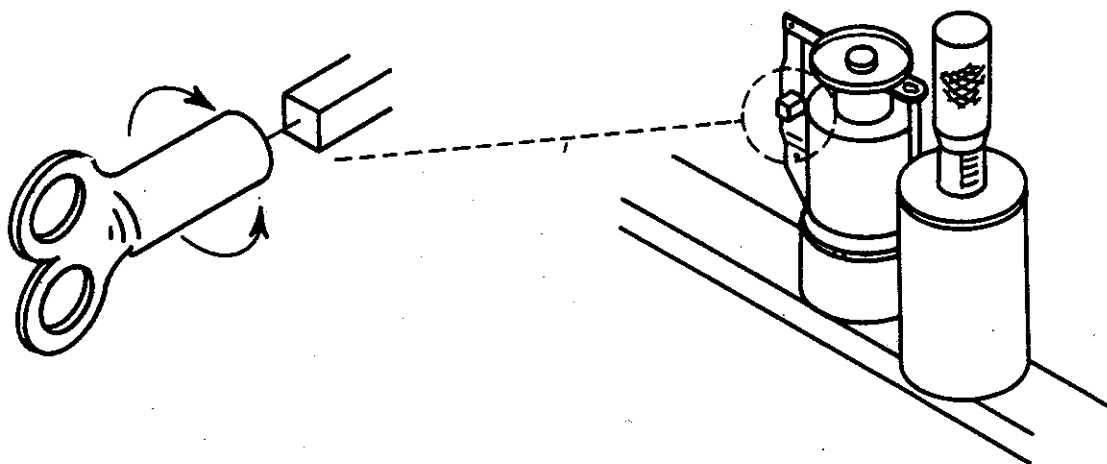


FIGURE 23 - 1

Chapter 24

MEASUREMENT OF WAVELENGTH IN FREE SPACE

Some of the kinds of waves treated in this manual are: waves of current, waves of potential difference, waves of charge density, waves of electric fields and waves of magnetic fields. A fundamental dimension of any wave motion is the linear distance between any two consecutive points that are in phase. This distance is known as the wavelength of the particular wave. Figure 24 - 1 shows a transverse wave comprised of tiny particles of a string, each exercising its own motion due to the disturbance of the wave. The arrows are vectors representing the direction of the velocity of each particle. The lengths of the arrows represent the relative magnitude of the velocity of each particle. A wavelength is defined as the distance between two particles on consecutive cycles of the wave having exactly the same amount of velocity and direction of velocity at the same instant in time. Thus, in order to find the wavelength, we need only determine which particles on each wave are behaving exactly the same, and measure the distance between them. This distance, one wavelength, is denoted by the Greek letter Lambda (λ).

For any given frequency of a wave, there is one and only one wavelength. This relationship is expressed by the equation $f\lambda = K$, where f is the frequency, λ is the wavelength, and K is a constant. Thus, we can see that the wavelength can be determined if we know the frequency and the value of the constant.

In this experiment, the wavelength will be measured by reading the distance corresponding to two similar meter readings, (minimum to minimum, maximum to maximum, etc.) When this distance is determined, the experimenter will have found one-half the wavelength. One must remember that with microwaves, one deals with rectified power. Therefore, in order to determine the correct wavelength, the distance must be doubled.

1. The equipment must be placed into the ready condition as outlined in Chapter 4 with the following exceptions:

- a. Remove the plug on the coaxial cable from the pin-jack output of the receiver assembly and connect it to the pin-jack output of the sliding probe.
- b. Place the variable flap attenuator at its maximum attenuation position (30 db).
- c. Place the selector switch on the front panel of the power supply to its "AMPLIFIED" position.
- d. Using the "AMP. ZERO ADJ." knob on the front panel of the power supply, set the meter to read zero.
- e. Adjust the variable flap attenuator to obtain a meter reading of 60.

2. Position the receiver assembly so that the zero of its vernier falls at the 14 centimeter mark on the long scale. This will act as a reflector to set up standing waves.
3. Move the receiver assembly slowly to the right until a minimum meter reading is obtained.
4. Record the exact reading of the long scale with the aid of the vernier on the receiver assembly.
5. Continue moving the receiver assembly to the right until the next minimum is noted on the meter. Do this precisely.
6. Record the exact reading of the long scale with the aid of the vernier on the receiver assembly.
7. Subtract to find the difference between the two scale readings. This equals the distance in centimeters between two minima.
8. Since we are dealing with rectified voltage forms, the distance between the two minima is one-half wavelength. Multiply this value by two to obtain the wavelength in free space.

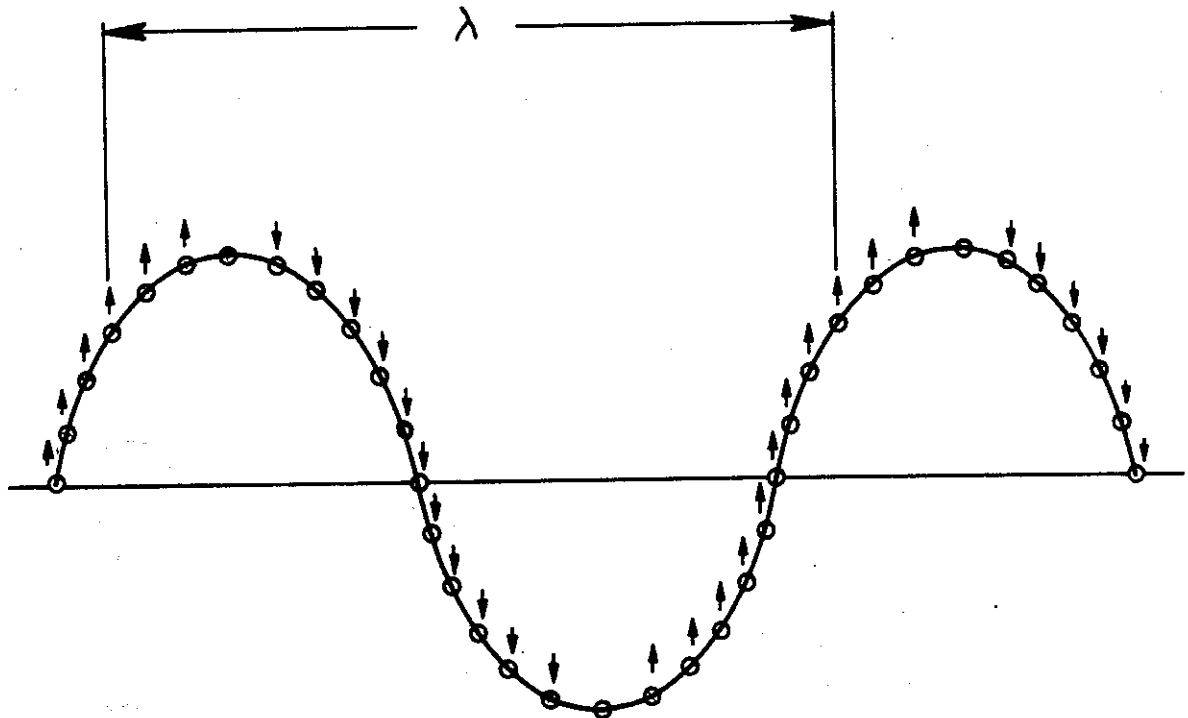


FIGURE 24 - 1

Chapter 25

MEASUREMENT OF WAVELENGTH IN WAVEGUIDE

In waveguide, the wavelength is longer than the corresponding wavelength in free space. Any wave actually possesses two velocities; the group velocity and the phase velocity. The group velocity is the velocity at which the envelope of an audio modulated signal travels. This envelope is a standing wave set up in the waveguide by high-frequency oscillations. The high-frequency oscillations appear to move at a velocity greater than the speed of light. This higher-than-the-speed-of-light velocity is called the phase velocity. When the equation $v = f\lambda$, is used for a waveguide, the velocity measured is phase velocity. Since the frequency is determined by the klystron, which is constant, the wavelength must be greater, (since the phase velocity is greater than the speed of light). This wavelength is the wavelength in waveguide and is related to the free-space wavelength by the equation:

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}}$$

where (λ_g) is the wavelength in waveguide, λ is the free-space wavelength and "a" is the broad-wall dimension of the waveguide.

1. The equipment must be placed into the ready condition as outlined in Chapter 4 with the following exceptions:

- a. Remove the plug on the coaxial cable from the pin-jack output of the receiver assembly and connect it to the pin-jack output of the sliding probe.
- b. Place the variable flap attenuator at its maximum attenuation position (30 db).
- c. Place the selector switch on the front panel of the power supply to its "AMPLIFIED" position.
- d. Using the "AMP. ZERO ADJ." knob on the front panel of the power supply, set the meter to read zero.
- e. Adjust the variable flap attenuator to obtain a meter reading of 60.

2. Position the receiver assembly so that the zero of its vernier falls at the 14 centimeter mark on the long scale. This will act as a reflector to set up standing waves.

3. Loosen the locking screw on the base plate of the sliding probe and slowly slide the probe along the slotted line. Note the meter deflections as the probe is moved. Stop at maximum point and increase the attenuation so that the meter reads 90. Slide the carriage along and readjust the attenuation so that the meter never exceeds 100.

4. Near the left end of the slotted line, locate a minimum point of field strength. This will correspond to a minimum meter reading. Note the position of the sliding probe by use of the vernier and scale on the sliding probe base plate and the slotted line. Do this precisely.

5. Slowly move the sliding probe to the right from this minimum point until the next minimum point is indicated on the meter. Record the position of the sliding probe at this point.

6. Calculate the distance between these two minima. This distance corresponds to one-half the wavelength in waveguide. Multiply this result by two to obtain the wavelength in waveguide. Verify this result by measuring the wavelength in free space as outlined in Chapter 24, "Measurement of Wavelength in Free Space" and substituting the values into the equation for wavelength in waveguide given at the beginning of this chapter. How good are your results?

81	10.09	>	2.01	$\begin{array}{r} 4.7 \checkmark \\ 6.80 \\ \hline 2.106 \end{array} \begin{array}{l} 8.96 \\ 2.16 \end{array}$
83	8.08	>	2.16	
78	5.92	>	2.33	
81	3.59	>		

Chapter 26

PHASE SHIFT

Phase shift of microwaves occurs whenever the speed of propagation of the wave is changed. If the speed is decreased, the wave will arrive at a point at some later time. If the speed is increased, the arrival of the wave is hastened. In each case, the position and direction of any point on the wave at the location at which the measurement is being taken is somewhat different. Thus, a shift in phase has been accomplished.

The speed of the wave can be changed by changing the medium through which the wave travels. If a medium of higher optical density is placed in the path of the wave, the wave speed will decrease. If a medium of lower optical density is placed in the path of the wave, the wave speed will increase. Changing the media changes the impedance of the line. Therefore, we can refer to any substance which causes a phase shift as a substance which changes the impedance of the line. In this experiment, the impedance of the line will be changed by inserting a card of high optical density material into the waveguide. We shall measure the location of a minimum power point without the phase shifter and, after inserting the phase shifter, measure the location of the same minimum power point. From the difference in location, we shall calculate the degree of phase shift. Minima, rather than maxima, are used because they are sharper than the maxima and, thus, more easily and precisely located.

1. The equipment must be placed into the ready condition as outlined in Chapter 4 with the following exceptions:
 - a. Remove the plug on the coaxial cable from the pin-jack output of the receiver assembly and connect it to the pin-jack output of the sliding probe.
 - b. Place the variable flap attenuator at its maximum attenuation position (30 db).
 - c. Place the selector switch on the front panel of the power supply to its "AMPLIFIED" position.
 - d. Using the "AMP. ZERO ADJ." knob on the front panel of the power supply set the meter to read zero.
 - e. Adjust the variable flap attenuator to obtain a meter reading of 60.
2. Position the receiver assembly so that the zero of its vernier falls at the 14 centimeter mark on the long scale. This will act as a reflector to set up standing waves.
3. Starting with the sliding probe at its extreme left position, move the probe slowly to the right until the first minimum is noted on the meter. Record the position of the probe by use of the vernier on the sliding probe and the scale on the slotted line and the meter reading.

4. Insert the phase shifter end of the attenuator-phase shifter combination laterally into the extreme right-hand end of the slotted line. Is the meter reading changed? What does this indicate? Record the meter reading.

5. In order to ascertain in which direction the phase has been shifted, move the probe slightly to the right and left of the position found in Step 3. In Step 3, a minimum point was obtained. Therefore, any shift in phase would make the meter reading greater. The direction moved by the probe which causes the meter reading to decrease is the direction in which the phase shift occurred.

6. Moving in this direction, locate the same minimum point on the meter which was obtained in Step 3. What is the position of the probe? Record the meter reading and the probe position.

7. In order to calculate how much phase shift has occurred, the displacement of the minimum point must be known. Subtract the second reading from the first reading of the probe position. What has been the displacement of the minimum point?

8. Calculate the wavelength following the procedure outlined in Chapter 25.

9. What fraction of the guide wavelength is the displacement of the minimum point? Since one wavelength corresponds to three hundred and sixty degrees in phase of the wave in the waveguide, what is the degree of phase shift?

Sample Solution:

$$\text{Guide wavelength} = \lambda_g = 3 \text{ Cm}$$

$$\text{Displacement of Minimum} = \Delta X = 0.5 \text{ cm}$$

$$\frac{\Delta f}{\lambda} = \text{fraction of guide wavelength shifted}$$

$$\frac{0.5 \text{ cm}}{3 \text{ cm}} = \frac{1}{6} \text{ guide wavelength}$$

One guide wavelength corresponds to 360° . Fraction of guide wavelength shifted times degrees equals degrees of phase shift.

$$(1/6) (360^\circ) = 60^\circ \text{ phase shift}$$

Chapter 27

MEASUREMENT OF THE SPEED OF LIGHT

In Chapter 24, "Measurement of Wavelength in Free Space", the relationship between the frequency and the wavelength of a wave is shown to be $f\lambda = K$. The value of the constant K is the speed of the wave. If one is dealing with light or any electromagnetic wave in free space, the speed is the speed of light and is denoted by the small letter, c . Thus, the above equation for the speed of a wave in free space becomes $f\lambda = c$, which is the defining equation for the universal constant known as the speed of light. This constant, as shown on the Chart of Electromagnetic Radiation, is in a vacuum,

$$c = 2.99793 \times 10^8 \text{ M/sec.}$$

1. Measure the frequency as outlined in Chapter 22, "Frequency Measurement and Theory".
2. Measure the wavelength as outlined in Chapter 24, "Measurement of Wavelength in Free Space".
3. Having obtained the values for f and λ in the equation, multiply them to obtain the value of the speed of light.
4. Retune the klystron using the procedure outlined in Chapter 23, "Tuning of Klystron".
5. Repeat steps 1 - 3 above to obtain value for c , the speed of light.

Since all electromagnetic radiation propagates at the same speed, referring to the chart we will see that the correct value should be 2.99793×10^8 M/sec. or 186,273 miles per second.

There are two principal potential sources of error in the experiment which may result in a reading of the speed of light somewhat different than the standard. Since we are reading to only two significant figures on the vernier, this may cause as much as a 4% error. Further, the calibration of the frequency meter may introduce as much as a 5 or 6% error into the computation. These errors may compound to a 9% possible error in the final computation.

Chapter 28

SINGLE-SLIT DIFFRACTION

It is an established fact that light travels in a straight line. Because of this, radar and microwave communications must be constructed on a line of sight basis. There is, however, a phenomenon which would seem to disprove the fact of rectilinear propagation. When light passes through a very narrow slit, the wave appears to spread out. It would be assumed that the light would travel in a straight line from this slit. Christian Huygens, viewing this phenomenon, postulated the theory that every point on an advancing wavefront is itself, the source of spherical wavelets. Thus, the slit, being narrow enough, would act as one point on the wavefront and spherical wavelets would be transmitted from it.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Remove the transmitting horn from the end of the main waveguide.
3. Place a piece of aluminum foil over the output end of the main waveguide line into which a slit of width 0.2λ has been cut.
4. Place the receiver assembly so that the zero of its vernier falls at the 14 centimeter mark on the long scale with its horn facing the main waveguide.
5. Adjust the attenuator to obtain a meter reading of 60.
6. Move the receiver assembly in an arc around the end of the main waveguide. Note the meter reading as the receiver leaves the line of sight of the main waveguide. What does this indicate? Do these results verify Huygens' principle?
7. Repeat step 6 moving the receiver assembly in an arc whose plane is perpendicular to the plane of the board.

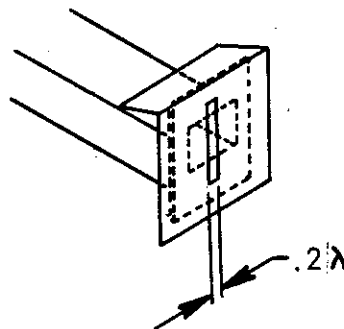


FIGURE 28 - 1

Chapter 29

DOUBLE-SLIT INTERFERENCE

In his arguments supporting the wave theory of light, Christian Huygens states that every point on an advancing wavefront is a generator of spherical wavelets. Therefore, any wave-motion is an extremely complex combination of many advancing waves. Since each point transmits its own waves, a great many interferences must occur. This is, in fact, the case. The Chart of Electromagnetic Radiation shows, in the section on interference, the interferences of two wavelets' waves. We can investigate these interference patterns in microwaves quite simply.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Remove the transmitting horn and add the waveguide bend so that the main waveguide line faces the front of the board.
3. Attach the transmitting horn to the output end of the waveguide bend so that the broad and narrow walls of the waveguide horn are coincident with those of the waveguide bend.
4. Attach one High-Gain horn to the transmitting horn.
5. From a good reflector (a piece of aluminum foil or sheet metal will suffice) about one foot square, cut two parallel slits whose widths are one-half wavelength and separation (measured from the center of each slit) is two wavelengths. If a piece about five inches is left above the slits, the metal can be bent in order to facilitate placing the slits in front of the transmitting High-Gain horn. See Figure 29 - 1.
6. Hang this piece in front of the transmitting High-Gain horn taking care to center the slits in front of the aperture of the horn.
7. Place the flap attenuator at its 3 db position.
8. The receiver assembly is to be used without a High-Gain horn. With the receiver assembly horn facing the transmitter, move the receiver assembly horizontally across the transmitting High-Gain horn from your right to left noticing the meter reading as the distance is transversed. At points where wave crests reenforce each other greater meter readings will be obtained. At points of destructive interference, where a crest meets a trough, the readings will be lower.
9. Starting at a position such that the receiver assembly horn is almost touching the plate with the slits, move horizontally across the plate from right to left. At each maximum meter reading, plot the horizontal distance from the center of the transmitting High-Gain horn against meter reading.

$$d = 2\lambda$$

10. Repeat step 8 from distances further away from the transmitting High-Gain horn moving away one inch at a time.

11. For each distance from the transmitting High-Gain horn, plot a graph showing maxima against horizontal distance from the center of the transmitting High-Gain horn. This shows the interference pattern for the double slit and demonstrates Huygens' Principle of Spherical Wavelets. If the energy travelled straight out from the slit, there would be no interference. Since there is interference, the waves must be of a shape similar to that shown on the Chart of Electromagnetic Radiation. Each slit can be considered a point on the advancing wavefront.

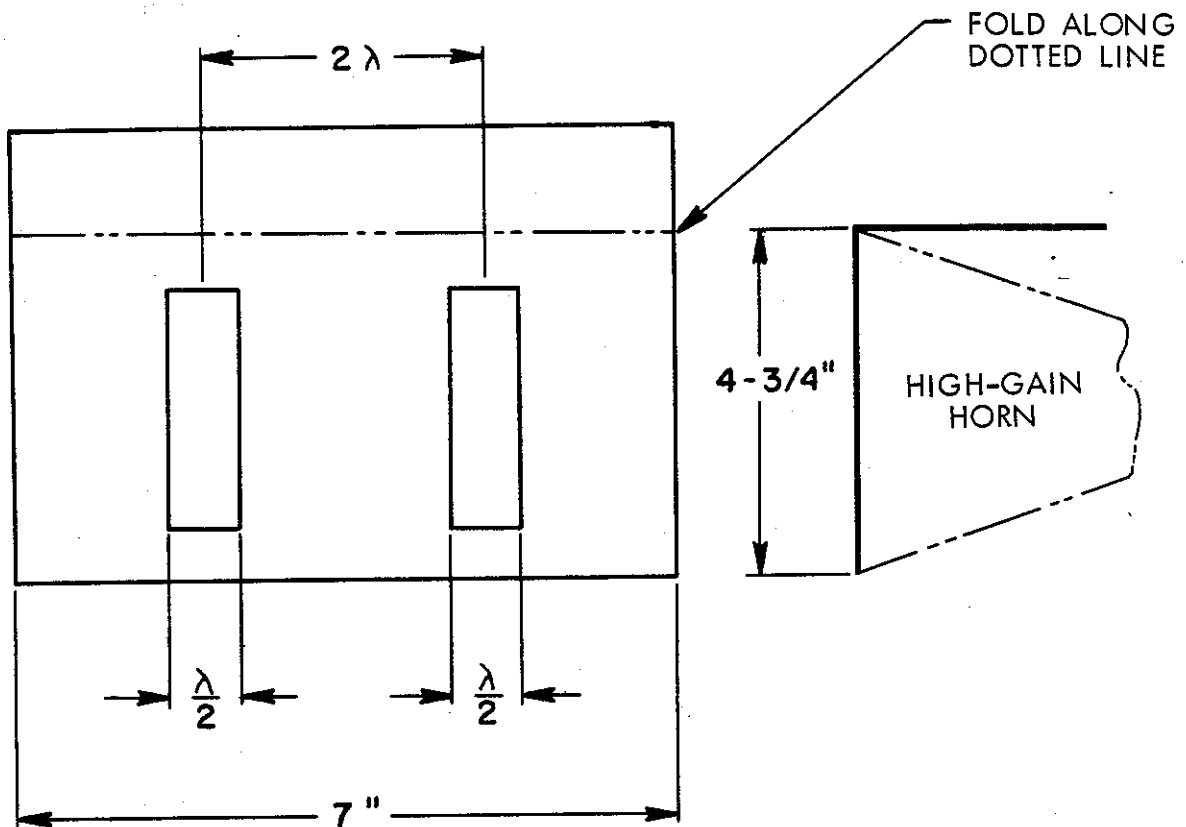


FIGURE 29 - 1

Chapter 30

INTERFERENCE FROM TWO REMOTE SOURCES

Referring to Figure 30 - 1, the energy which travels directly to the receiver assembly from the transmitting horn travels along the path OC. Some energy is taken out of the transmitted beam by the small mirror and is reflected from the large reflector into the receiver assembly along the path OABC. From the geometry involved, it is clear that path length OABC is greater than path length OC. By varying the position of the large reflector, we can change the length of the path and, thus, the phase of the wave traveling along OABC. When the two beams are caused to arrive in phase, their amplitudes will add and a maximum meter reading will be obtained. When they are caused to arrive out of phase, their amplitudes will subtract and a minimum meter reading will be obtained. As the large reflector is moved away from the transmitter, the path length OABC becomes greater. Therefore, the amplitude of the wave detected at the receiver assembly will fall off according to the inverse square law. Since the amplitude of the signal OABC is decreasing and since maxima occur when the two signals, OC and OABC add, the subsequent maxima will have decreasing amplitudes. Since path length OC is constant, the maxima are proportional to the path length OABC.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Place one High-Gain horn each onto the transmitting horn and the receiving horn.
3. Place the receiver assembly at a distance of about three feet from the transmitting High-Gain horn on the laboratory table. Support the receiver assembly so that its height is the same as that of the transmitting High-Gain horn.
4. Adjust the flap attenuator to obtain a meter reading of 80.
5. Place the small mirror into the component stand in a vertical position and place this about six inches in front of the transmitting High-Gain horn, centered in the aperture of this horn. The angle of this mirror is to be such that the meter reading drops to 40. See Figure 30 - 1.
6. Place a large reflector (mirror, tin, fine-mesh metallic screen, etc.) approximately one foot square, to the right of the transmitting High-Gain horn in such a position that it receives the signal from the small mirror and reflects it into the receiver assembly. By observing the meter, one can tell when the signal is being reflected into the receiver assembly. When this occurs, the meter will show a greater reading. By correctly positioning the large reflector, the entire portion of the transmitted wave which is removed by the small mirror can be directed into the receiver assembly.
7. Measure the path length OABC when the large reflector is in a position such that signals OC and OABC add to give a meter reading of 80. Record the path length and the meter reading.

8. Carefully move the large reflector in the direction of the arrow in Figure 30 - 1 until the meter indicates the first minimum. This must be done slowly in order for the meter to give a true reading. Record the path length OABC and the meter reading at this point.
9. Again slowly move the large reflector in the direction of the arrow in Figure 30 - 1 until the meter indicates the next maximum. Record the path length OABC and the meter reading at this point.
10. Repeat steps 8 and 9 recording path length and meter reading for each maximum and minimum point.
11. Plot a graph of meter reading against path length OABC. This graph is a representation of the interference pattern resulting from the coincidence of the two waves.

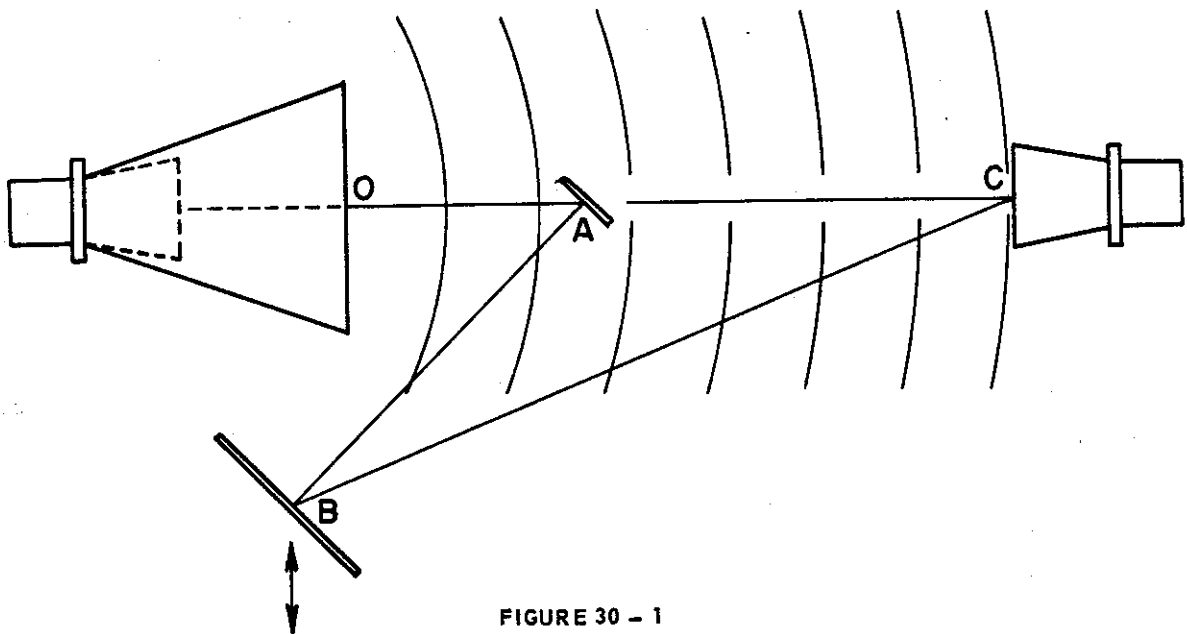


FIGURE 30 - 1

Chapter 31

THIN FILM INTERFERENCE

The phenomenon of thin film interference is visible to us all every day. If we look at water with some oil floating on its surface, we notice a rainbow effect. The colors which we see are caused by the interference among the light rays reflected by the various layers of the oil. In order for the interference to occur, the film of oil must be of the order of one half wavelength thick. This phenomenon is very difficult to study in visible light because of the exceedingly small wavelengths involved. In microwaves, however, the wavelengths are many times greater than those of visible light and, therefore, the "films" can be much thicker.

In this experiment, a half-reflecting surface will be used for the first layer of the thin film. The mirror shall be used for successive layers. The half-reflecting surface is to be constructed of a one foot square of gridded wire whose grids measure approximately 1.2 centimeters by 1.2 centimeters.

1. Place the equipment in the ready position as outlined in Chapter 4.
2. Place the receiver assembly alongside of the transmit horn, toward the rear of the board, facing in the same direction as the transmit horn. Angle the receiver assembly about 15° toward the line of transmission. See Figure 31 - 1.
3. Place a mirror in a component stand in front of the transmitting horn at the 20 centimeter mark on the long scale. The edge of the mirror should be opposite the scale mark. See Figure 31 - 1. Slowly turn the stand clockwise in order to maximize the meter reading. The reading may also be maximized by moving the mirror slightly to the right or left. If the meter should go off scale, increase the attenuation in the line with the variable flap attenuator. At the position of maximum reflection, adjust the attenuator to give a meter reading to 50. If a reading of 50 is unattainable, use the signal amplifier as follows:
 - a. Set the attenuator at 30 db.
 - b. Set knob to "AMPLIFIED".
 - c. Adjust meter to zero with "ZERO ADJ. KNOB".
 - d. Adjust attenuator to get meter reading of 50 db.
4. Place the half-reflecting surface into the other component stand and position this stand in front of the first stand with the planes of the reflectors parallel with each other. Observe and record the meter reading.
5. Slowly slide the mirror to the right along the long scale until a minimum meter reading is obtained. Record this reading and the distance moved.

6. Repeat step 5 beginning at the last recorded position.
7. Repeat step 6 as many times as necessary until the end of the long scale is reached.

The maxima and minima which are noted from the meter readings are analogous to the bands of color which one notices when observing this phenomenon in light. Microwaves are monochromatic, therefore, the signals either add or subtract to give varying meter readings. The thickness of the "thin film" required to cause microwaves to interfere can be calculated by subtracting any two successive distances as recorded in steps 5, 6, and 7.

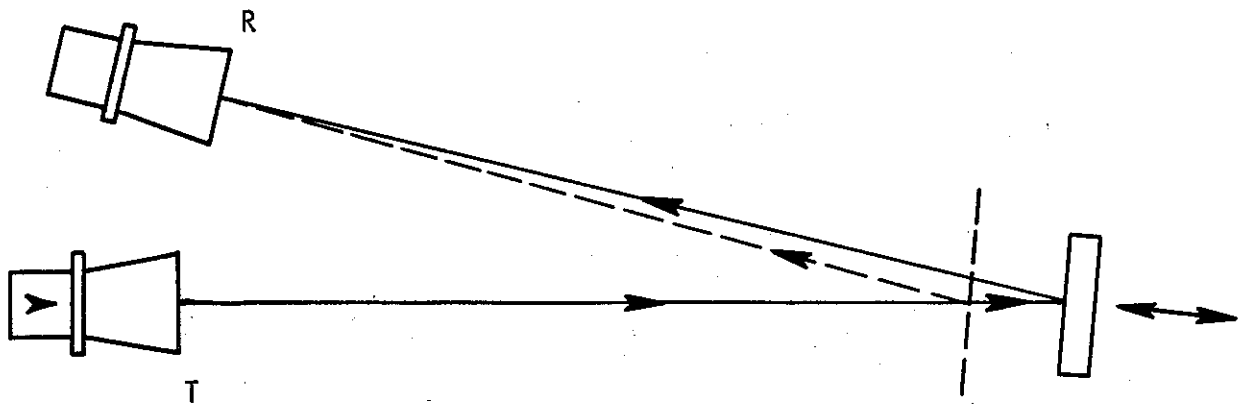


FIGURE 31 - 1

Chapter 32

MICHELSON'S INTERFEROMETER

In performing this experiment, the user must take great care in correctly determining the distances between the various reflectors and the transmitting horn and receiving horn. The path lengths which the microwaves travel are quite long. Since the power output of the klystron is relatively low, the meter indication is very sensitive to small distances.

Referring to Figure 32 - 1, we can see the paths which the energy takes as it travels from the transmitter to the receiver.

As the energy emitted from the transmitter at T is incident upon the half-reflecting surface at O, it is split into two beams, each one-half the intensity of the transmitted beam. By adjusting the angle which the half-reflecting surface makes with the direction of the transmitted energy, the two half-intensity beams can be caused to be mutually perpendicular. These half-intensity beams proceed outward from the half-reflecting surface until they are reflected by the plane surfaces of reflectors A and B. Let us examine the beam traveling from the half-reflecting surface O to reflector A. This beam is reflected at point A directly back upon itself and is incident upon the half-reflecting surface at point O. At this time, due to the half-reflecting surface, the reflected ray AO, is again divided in half. A beam of one-half the intensity of AO is reflected back into the transmitting horn and a beam of one-half the intensity of AO is passed through the half-reflecting surface and incident upon the receiver at point R. Similarly, from reflector B, a beam of one-half the intensity of BO is reflected from the half-reflecting surface at point O and is incident upon the receiver at point R. Therefore, the intensity at R is one-half the intensity of the transmitted beam TO.

1. Place the equipment in the ready position as outlined in Chapter 4 with the following exceptions:
 - a. Place the waveguide bend on the end of the main waveguide line so that the waveguide is turned through 90° to face toward the front of the Ed-Set.[®]
 - b. Place a waveguide horn onto the output end of the waveguide bend in a position so the ribs of the horn are on the top and bottom of the horn. This is the transmitting horn.
 - c. Place one High-Gain horn onto this transmitting horn.
 - d. Place the other High-Gain horn onto the horn of the receiving assembly.
 - e. Connect the end of the coaxial cable to the pin-jack extending from the top of the crystal detector of the receiver assembly.
2. Place the receiver directly in front of and facing the transmitter at a distance of four feet. This distance is measured from the plane of the large end of the transmitting High-Gain horn to the plane of the large end of the receiving High-Gain horn.
3. Varying the flap attenuator, obtain a meter reading of 20.

4. Slightly adjust the lateral position of the receiver assembly to obtain a maximum meter reading, taking care to consistently maintain the four feet distance from the transmitter. When the meter is at its maximum reading for this distance, adjust the flap attenuator to give a meter reading of 80. For the rest of the experiment, do not touch the flap attenuator.

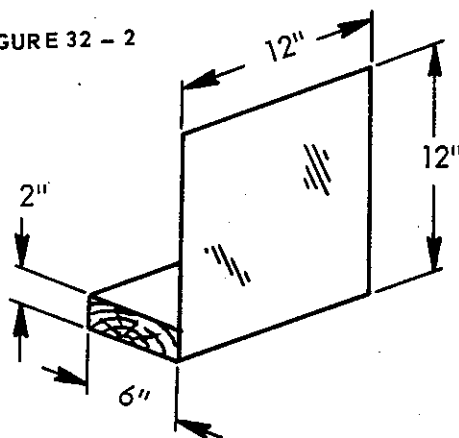
5. Place the half-reflecting surface midway between the reflector and the transmitter with its plane at 45° angle with the direction of propagation. The half-reflecting surface is to be constructed of a one foot square of gridded wire whose grids are approximately 1.2 centimeters by 1.2 centimeters. An imaginary vertical center line drawn at 0 is to be perpendicular to line TB.

6. Place a reflector, Figure 32 - 2, along line OA so that the length of OA is equal to the length of OB and OA is perpendicular to TB at point O.

7. Place the receiving assembly, with the large end of its horn facing the half-reflecting surface, along line OR so that the length of OR is equal to the length of OB and OR is perpendicular to TB at point O. By carefully adjusting the position of the horn, obtain a meter reading of 40. At this reading the distance OR may not be precisely equal to OB. This is due to various reflections of the energy from nearby objects.

8. Marking the position of reflector B, slowly move it away from the half-reflecting surface along line OB. Note that the meter will swing from the maximum at position B to a minimum to a maximum, etc., as the reflector is moved along OB. This meter swing is caused by interference between the microwaves from reflectors A and B. When the meter reads 40 (a maximum), the phase of the two beams at R, is the same. When the meter reads anything below 40, the two waves are arriving at R out of phase due to difference in path lengths. By measuring the linear distance traveled by reflector B, we can obtain the length of one-half wavelength. (This is only one-half the wavelength because our meter is indicating half-wave rectified power).

FIGURE 32 - 2



(POLISHED ALUMINUM
SHEET AND 2 X 6
USED IN POSITION "A"
AND "B")

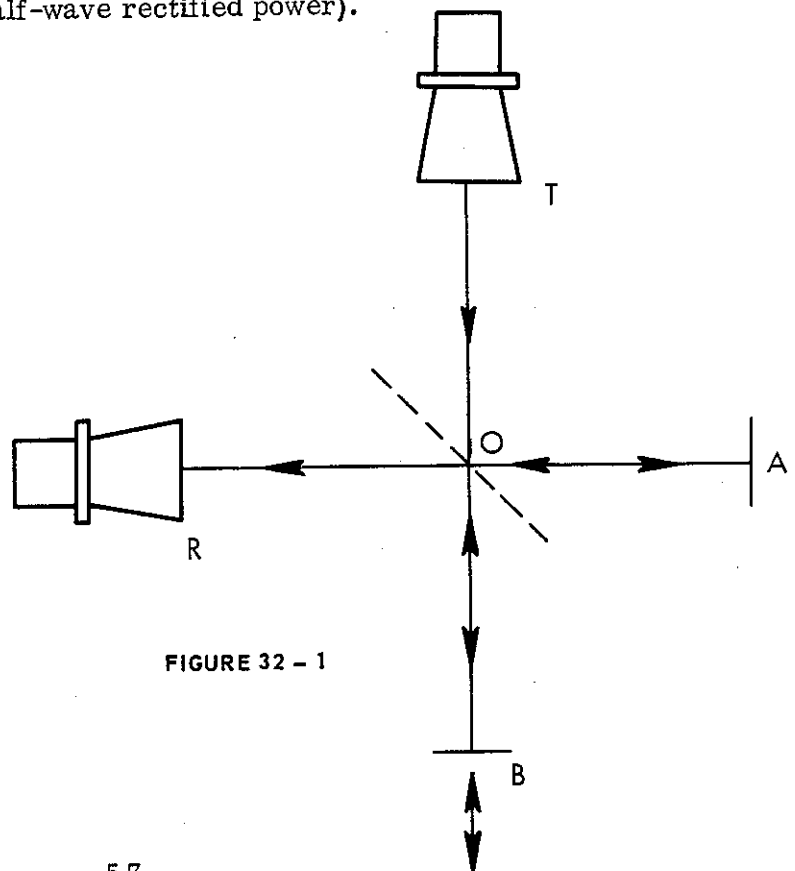


FIGURE 32 - 1

Chapter 33

OPERATION OF RADAR

In the experiments on Reflection, we actually investigated the principle of Radar. When the energy leaves the transmitter of a radar set, timing circuits are energized. The energy reflects from the target and returns to the receiving antenna. The receipt of the energy stops the timing circuits. From the elapsed time between the transmitted and received signals, the distance of the target is calculated. In order to fix any object in three dimensional space, three coordinates are required. These are: range (distance), azimuth, and altitude. Range is calculated from the time of the return echo. Azimuth and altitude are calculated by knowing the attitude of the antenna with respect to a point of the compass and zero degrees in elevation.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Remove the transmitting horn.
3. Attach the waveguide bend to the main waveguide line so that the main waveguide line is bent to face the front of the board. Be sure that the broad and narrow walls of the waveguide bend are coincident with the broad and narrow walls of the main waveguide line.
4. Attach waveguide horn to the output end of the waveguide bend taking care that the broad and narrow walls of the waveguide horn are coincident with the broad and narrow walls of the main waveguide line.
5. Attach one High-Gain horn each to the transmitting and the receiving horns.
6. Place the receiver assembly on the board alongside the transmitting High-Gain horn facing in the same direction as the transmitting High-Gain horn. See Figure 33 - 1.
7. Using a good reflector (refer to the list compiled in the performance of Chapter 6, "Reflection by Electrical Conductors"), reflect the transmitted signal into the receiver assembly. The reflector should be at least one foot square and be held approximately five feet in front of the transmitting horn. Adjust the position of the receiver assembly to obtain a maximum meter reading. This is the method of operation of most commercial radars.
8. Try this experiment with the audio circuit.
9. Try again with a large reflector (about 3 x 3 feet) and using the signal amplifier. Remember to zero adjust with the flap attenuator at 30 db whenever you use the signal amplifier.
10. Try this experiment with a wood door in the microwave path.

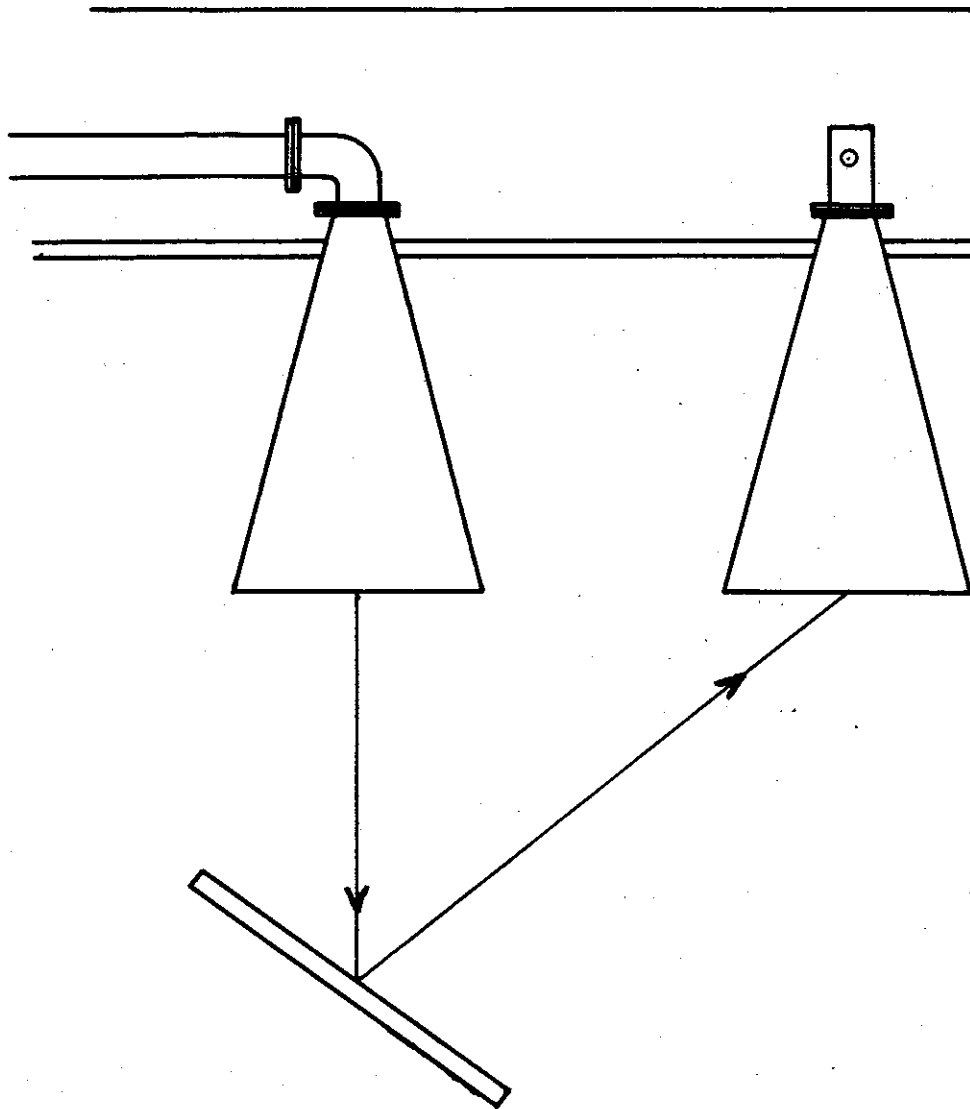


FIGURE 33 - 1

Chapter 34

WEATHER DETECTION

Recently the U. S. Weather Bureau has been using radar in order to predict weather conditions. One may ask how a cloud can appear on a radar scope because only those things which reflect the transmitted signal are detected. A cloud is composed of millions of tiny water particles. As we know, light will pass through water. Since this is the case with light, does all electromagnetic energy pass through water? If so, what reflects the energy into the receiver? We shall experiment with water to see its properties with respect to microwaves.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Place the receiver assembly at a position with the zero line of its vernier at 22 centimeters on the long scale.
3. Adjust the flap attenuator to obtain a meter reading of 80.
4. Insert a dry sponge or paper towel between the horns and note the meter reading.
5. Wet the sponge or towel. Squeeze the excess water from it. Again place it between the horns. Note the meter reading.
6. Remove the sponge from between the horns.
7. Place a clear, empty water glass between the horns. Because of the slight focusing due to the glass curved surface, move the glass slightly back and forth along the long scale to obtain a maximum meter reading.
8. Without moving the glass, slowly fill it with water. Note the meter reading.

From the experimental results, what conclusion can we draw about the transparency of water to microwaves? Does this explain how cloud formations can be detected on a radar scope?

Chapter 35

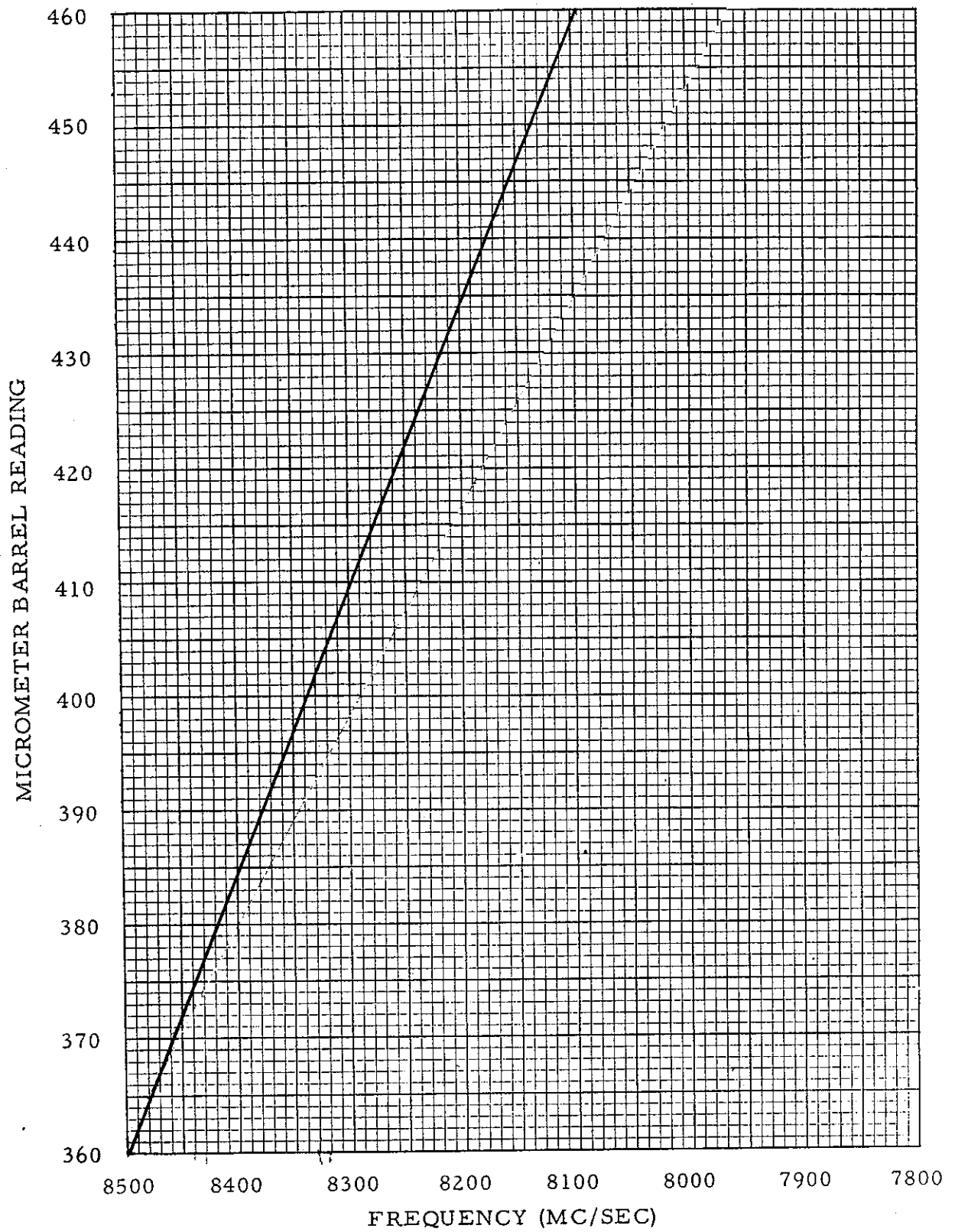
MICROWAVE RELAYS

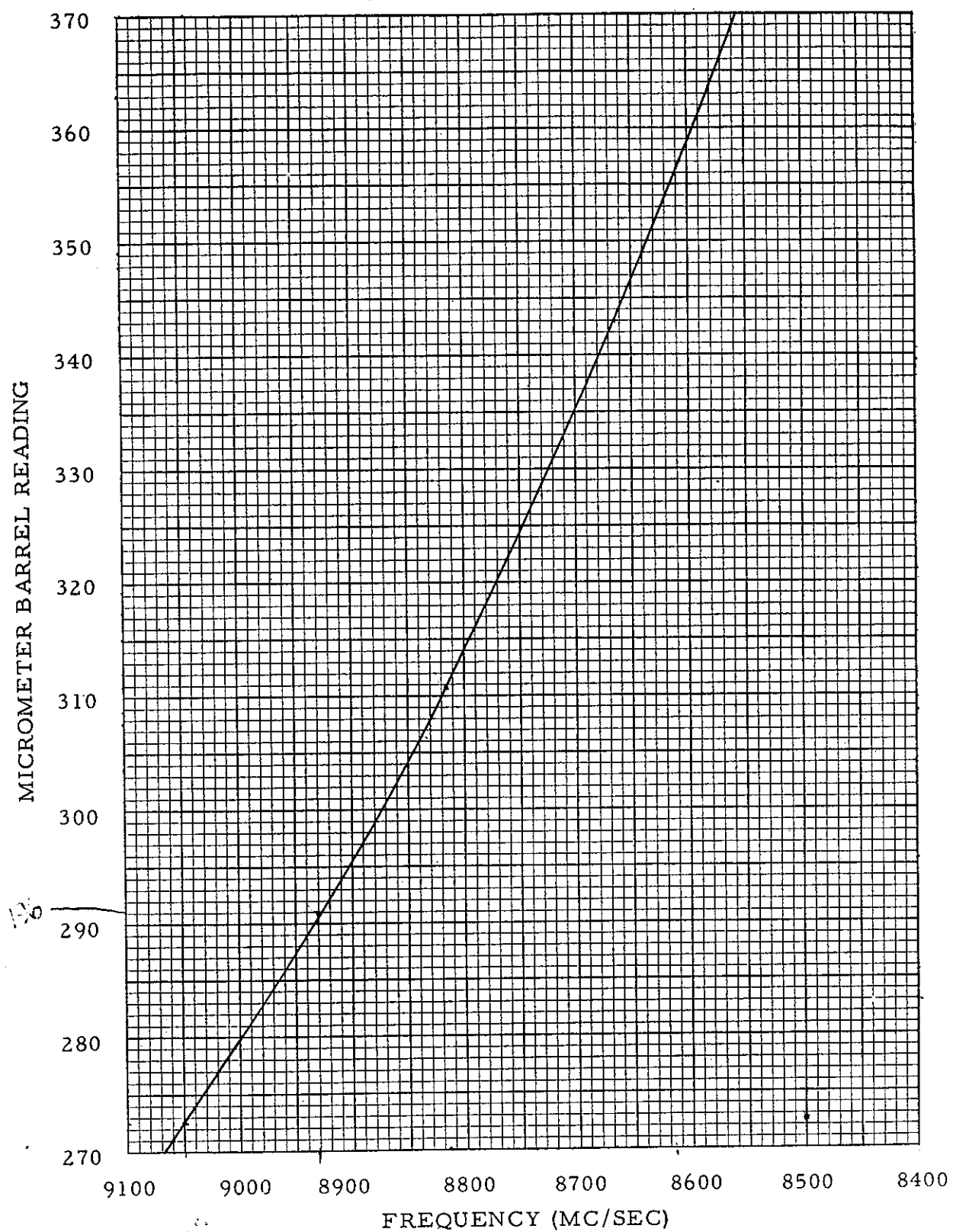
When microwave energy is transmitted through space, a constant wave (CW) frequency is sent from the transmitter to the receiver. No information is contained in this CW transmission except its frequency. If the klystron could be pulsed in a certain code, these pulses could be received and decoded at the receiver. This decoded message can be used to turn something on, to direct a rocket, to guide airplanes when landing, etc. The pulsing also serves to keep a receiver from accepting signals from all but one transmitter.

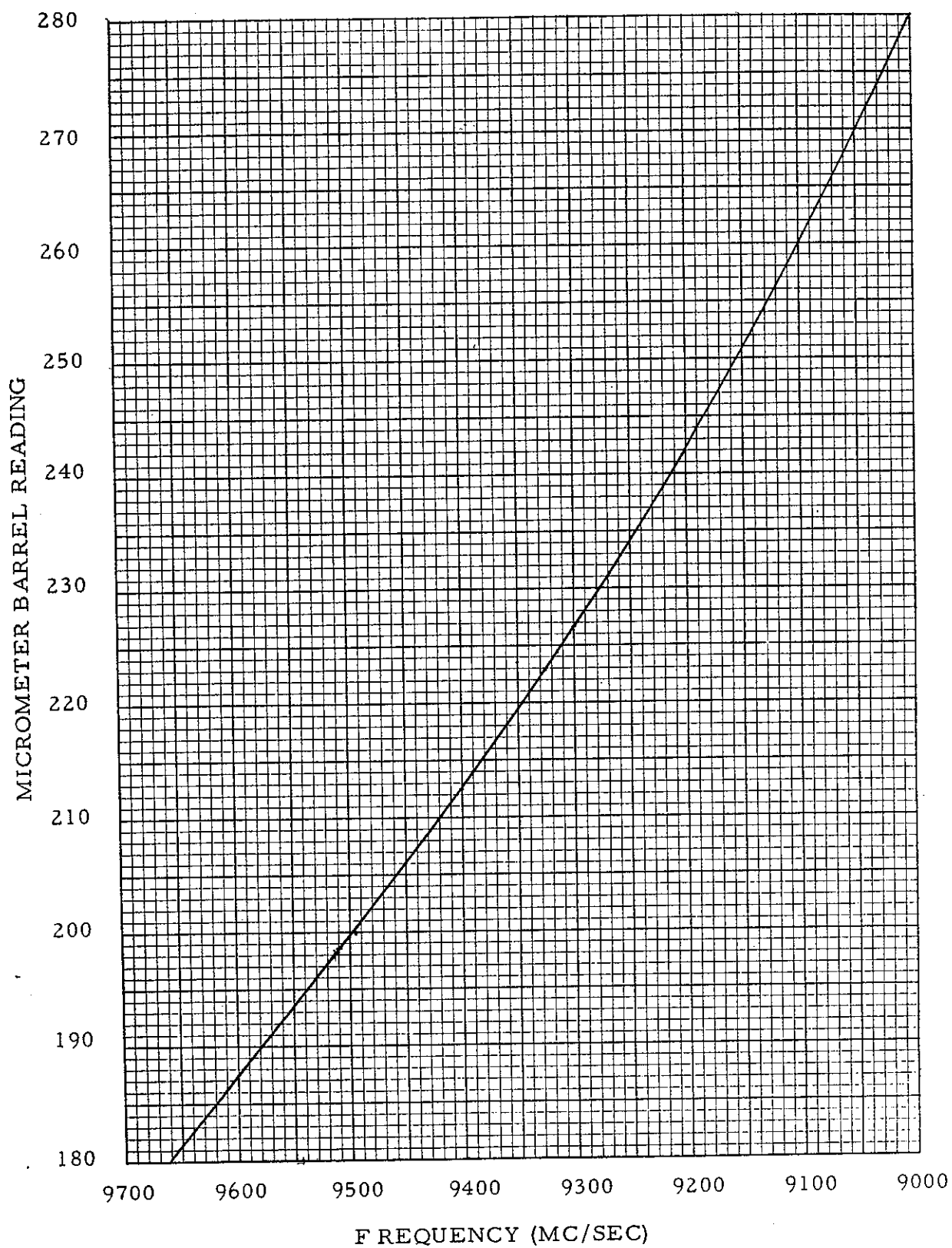
If the pulse, with which the klystron output is modulated, is a voice, the microwave transmitter and receiver act as a microwave relay. This is how long distance telephone calls are completed. To modulate the klystron, the voice coil output of a tape recorder or record player can be used.

1. The equipment must be placed into the ready condition as outlined in Chapter 4.
2. Plug a phone jack which is connected across the secondary of the voice coil into the Ed-Set jack marked "EXT. MOD.". (On some recorders and record players, there is an output marked "EXTERNAL SPEAKER". The modulation can be taken directly from there rather than connecting to the voice coil.)
3. The volume may be controlled at two places: the volume control on the tape recorder or record player, or the audio volume control knob on the Ed-Set.
4. Once the music or voice is being played, interrupt the path of the energy with any non-transparent substance. What is the result?
5. Your own voice can be transmitted by plugging the microphone into a tape recorder or any amplifier. Any external modulation can be used whose amplitude is about twenty volts.

APPENDIX 1







APPENDIX 2

INSTRUCTIONS FOR CHANGING CRYSTALS

It may be necessary in the use of the Budd-Stanley Model X4100 Microwave-Optics Ed-Set to change the crystals located in the two detectors, the sliding probe and the waveguide crystal detector. The replacement crystals must be type IN23B. These may be purchased in any electronics supply store or from Budd-Stanley. The following steps provide the procedures which should be followed.

Sliding Probe

1. Lock the sliding probe in the center of its travel in the slotted line by tightening the locking screw on the base of the sliding probe.
2. Disconnect the coaxial cable from the pin jack on the sliding probe.
3. Turn the knurled ring on the sliding probe counter-clockwise until the top of the probe is disconnected.
4. Holding down the clear plastic insulator with the tip of one finger, pry the crystal loose with the fingernails of the other hand.

CAUTION: When handling the new crystal, hold it by its white porcelain center portion. Grasping the crystal between the thumb and fore-finger by each end can cause the crystal to be burned out.

5. Place the crystal into the sliding probe.
6. Apply moderate pressure to the top of the crystal to insure that it is firmly seated.
7. Replace the top of the sliding probe and tighten the knurled knob finger tight.

Waveguide Crystal Detector

1. Remove the coaxial cable from the pin jack on the waveguide crystal detector.
2. Turn the knurled knob counter-clockwise in order to remove the top of the crystal holder.
3. Pry the crystal loose with the fingernails of one hand.
4. Being sure that the plastic grommet is well seated around the top of the hole for the crystal, place the new crystal into the hole. Apply moderate pressure to the top of the crystal to insure that it is firmly seated in its position.
5. Replace the top of the crystal holder and tighten it finger tight with the knurled knob.